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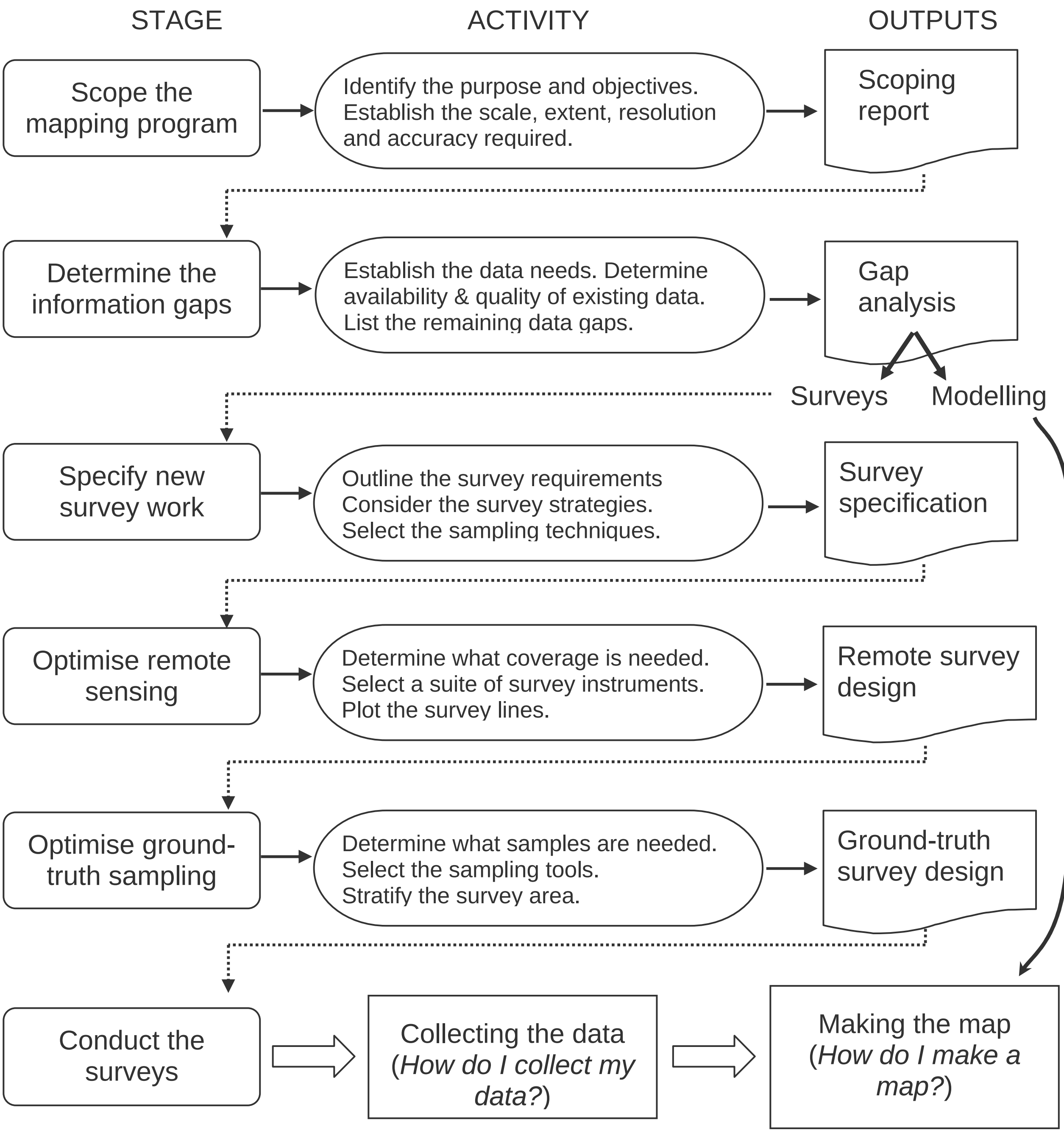
Close

What do I want to map?

R. Coggan & J. Populus

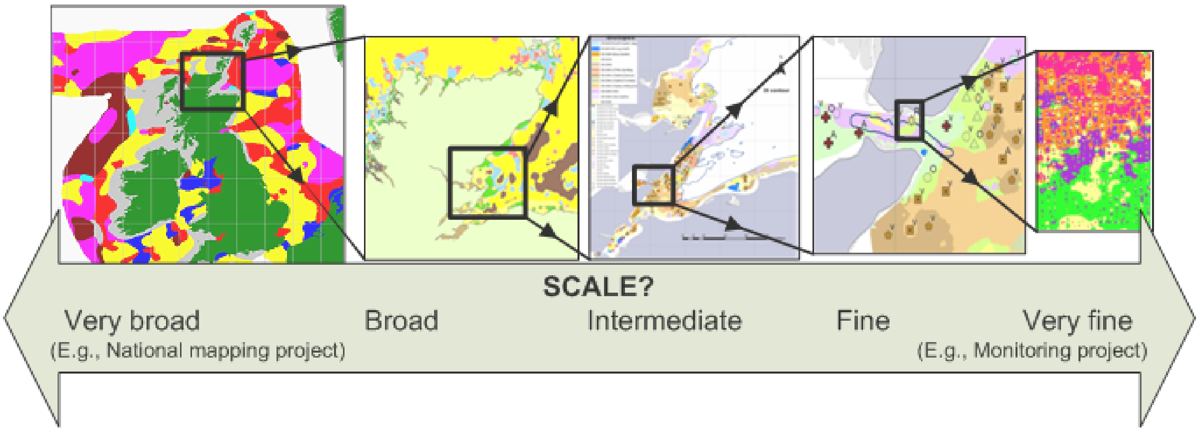
The aim of this section is to guide users through the planning stages of a mapping programme to ensure that the final products are fit-for-purpose and deliver the information required. As the mapping process can be very involved, it is important to have adequate consultation throughout the planning phase between the end users, the funders and the producers of the map so that each understands the scope of the project and the options available for undertaking the work. To help guide this planning and consultation, we divide the process into a series of stages (see flow diagram), each of which is described in the subsequent sections.



Flow diagram outlining the stages to be followed in planning a mapping programme.

Scope the mapping programme

The aim of the scoping exercise is to establish the purpose and objectives of the mapping programme to make it clear exactly what it is trying to achieve, and why it is needed. This knowledge will inform all the subsequent planning stages and determine precisely what is (or is not) required in the final mapped product. It is the responsibility of those who commission mapping programmes to make their requirements perfectly clear and they should be intimately involved in the scoping and planning process. The scoping exercise produces a scoping report that should be a shared document between the sponsors, managers, surveyors and mappers, and could form part of a contract specification.



Mapping scale and purpose

There is generally an inverse relationship between the information content (detail and resolution) of a map and the spatial area that it covers. Maps depicting large areas usually show generalised information, while those depicting small areas usually have a lot of fine detail. These different resolutions are commonly referred to as broad-scale and fine-scale maps, with intermediate-scale maps lying somewhere between.

Very broad scales are likely to be national mapping projects, while very fine scale surveys will probably target particular biota or habitat parameters for quality-monitoring purposes. Most marine management and spatial planning requires an assortment of habitat maps between these two extremes. Such broad-, intermediate- and fine-scale mapping exercises need somewhat different approaches and form different elements of a mapping or survey programme, so each will need scoping separately.

The scoping process will determine the area to be mapped (extent), the map scale (e.g. 1:250,000) and resolution (the smallest unit to be mapped), the spatial precision required (e.g. ± 50 m), how accurate the map should be and the level of detail needed in the habitat classification. Here there can often be a trade-off, improving the nominal accuracy of the map (measured by its success in predicting what habitat exists at a given point) by settling for a more generalised (less precise) description of the habitat (e.g. EUNIS level 3 instead of EUNIS level 4).

This part of the MESH Guide leads you through this scoping process, highlighting matters that you need to consider and capturing the results in a brief **Scoping Report** (a pro-forma is provided in the resource file Scoping Report pro-forma.doc To help in the decision making process, an interactive **Scoping Tool** is provided, in the form of a Flash® animation, that allows you to test and assess various scenarios before finalising the scoping report.

Links to other topics in the current section:

More information is provided in this section about The Scoping Process. Access to the Scoping Tool and guidance on how to use it are given in the section The Scoping Tool. The outcomes of the scoping process are captured in The Scoping Report. After completing the Scoping Report, the next section in the planning process is to Determine the Information Gaps

Links to Resources

Scoping Report pro-forma.doc

The Scoping Process

The scoping process can be broken down into two phases. The first is a high level consultation through which it is crucial to establish with absolute clarity the overall purpose and objectives of the mapping programme. This consultation should engage relevant stakeholders, particularly those who will commission the work, those who will use the results and those with experience of undertaking such projects, and should consider, *inter alia*:

- The needs of the end-users of the maps, as these identify the major drivers for the programme.
- The level of resources that will be required to deliver the programme
- The time scale on which it is reasonable to complete the programme
- Contingencies that may need to be met.

This first phase is essentially a feasibility study to establish whether there is a reasonable balance between the desired products and the available time and budget. Expectations may need to be revised in the light of fixed budget or time constraints, or additional resources sought to meet specific, critical needs.

When the purpose and objectives of the overall programme have been established, the scoping process can move to the second phase, considering the proposal in more detail. A large programme may need to be broken down into several elements, each addressing a different spatial scale and type of mapped output (broadscale to finescale). These different elements will have their own specific purpose and objectives and will therefore need scoping separately to establish the scale, extent, resolution and accuracy of the required maps, and therefore the likely effort required in any new survey work. This can usefully highlight mismatches between related mapping criteria, for example requesting high spatial accuracy for a broadscale map would appear to be unnecessary, and mapping at low resolution on site specific surveys is unlikely to provide much relevant detail. There is also the opportunity to consider how the nature of the area to be mapped and environmental conditions that are likely to be met during any survey work will affect the suitability of various survey tools and techniques. This will have a bearing on survey strategy and survey costs.

Any major anomalies identified in this second stage should lead to an iterative process of consultation and modification to arrive at a proposal that is realistic in its expectations. To help this scoping process, the MESH project has developed an interactive Scoping Tool, which is presented in the next section and can be used to facilitate the consultation process. The outcome of the scoping process should be captured in a formal scoping report which will act as both a framework for the mapping programme and a point of reference for the subsequent planning stages of the programme. A suggested format for this report is presented in the section entitled The Scoping Report.

Throughout the scoping process, the terms **Site**, **Area** and **Region** are frequently used to convey the concepts different spatial extents, but the lack of any definition of these terms can lead to misunderstanding during consultation and planning. MESH therefore offers the following definitions, and uses the terms to refer to a spatial hierarchy, as illustrated in the diagram below. A **Site** would normally be a specific location of interest, say a particular beach or offshore feature (e.g. disposal ground) with an extent up to ~10 x 10 km (generally, between 1 and 100 sq km). An **Area** would normally be larger than this, having some local geographical context such as an estuary or archipelago, or an extensive offshore feature such as the Dogger Bank or Anton Dornh seamount, with an extent up to ~100 x 100 km (generally between 100 and 10,000 sq km). A **Region** would be considered as a larger ecological unit such as the Eastern Channel or Irish Sea, with an area normally greater than 10,000 sq km. These definitions are not intended to be precise demarcations but rather an aid to conceptualising different spatial extents associated with mapping studies. Hence, one would normally think of broadscale maps summarising information over a Region or Area, intermediate scale maps showing a moderate amount of detail about the distribution of habitats in an Area or a large Site, and finescale maps providing detailed information on the variety and location of biotopes encountered at a Site.

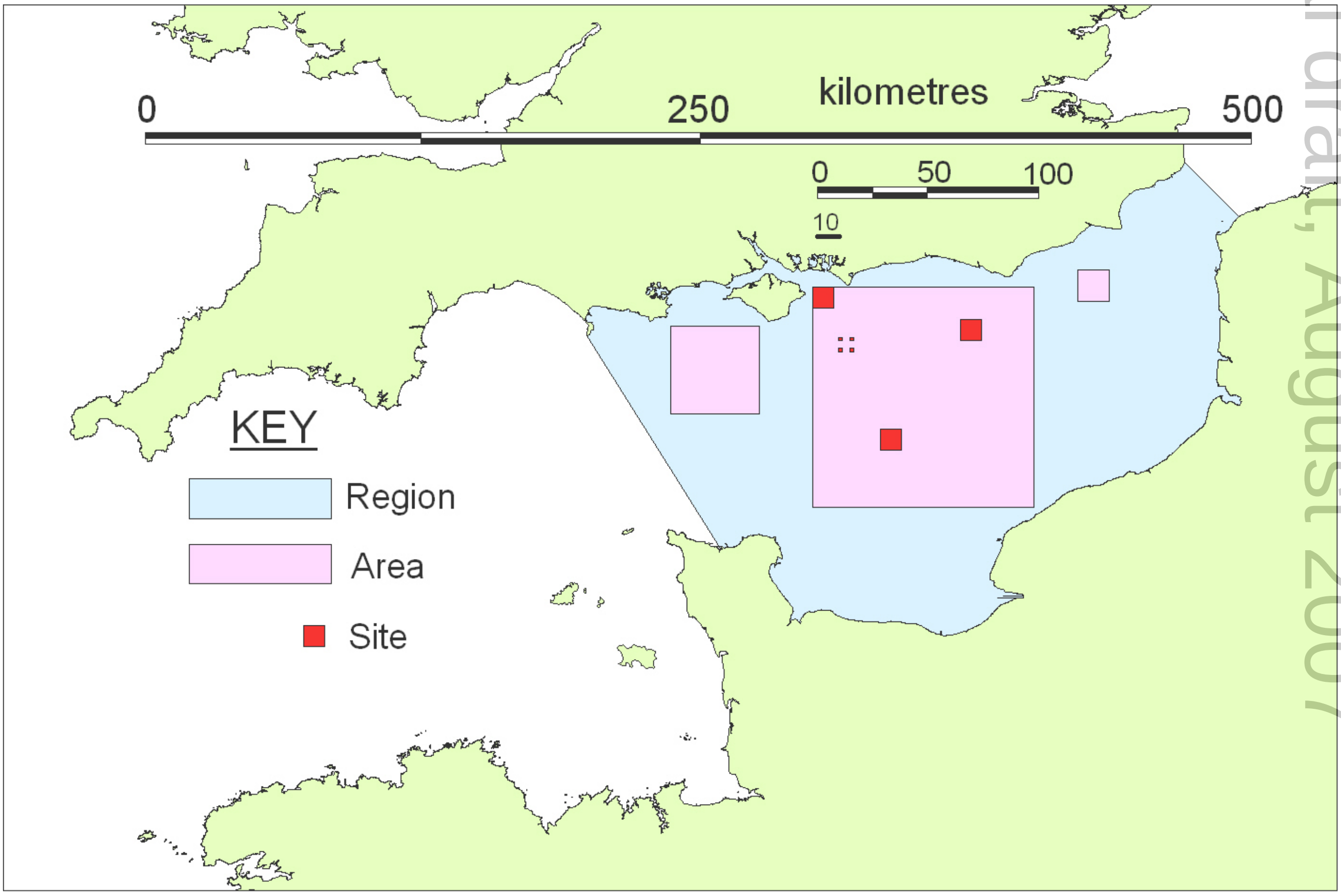


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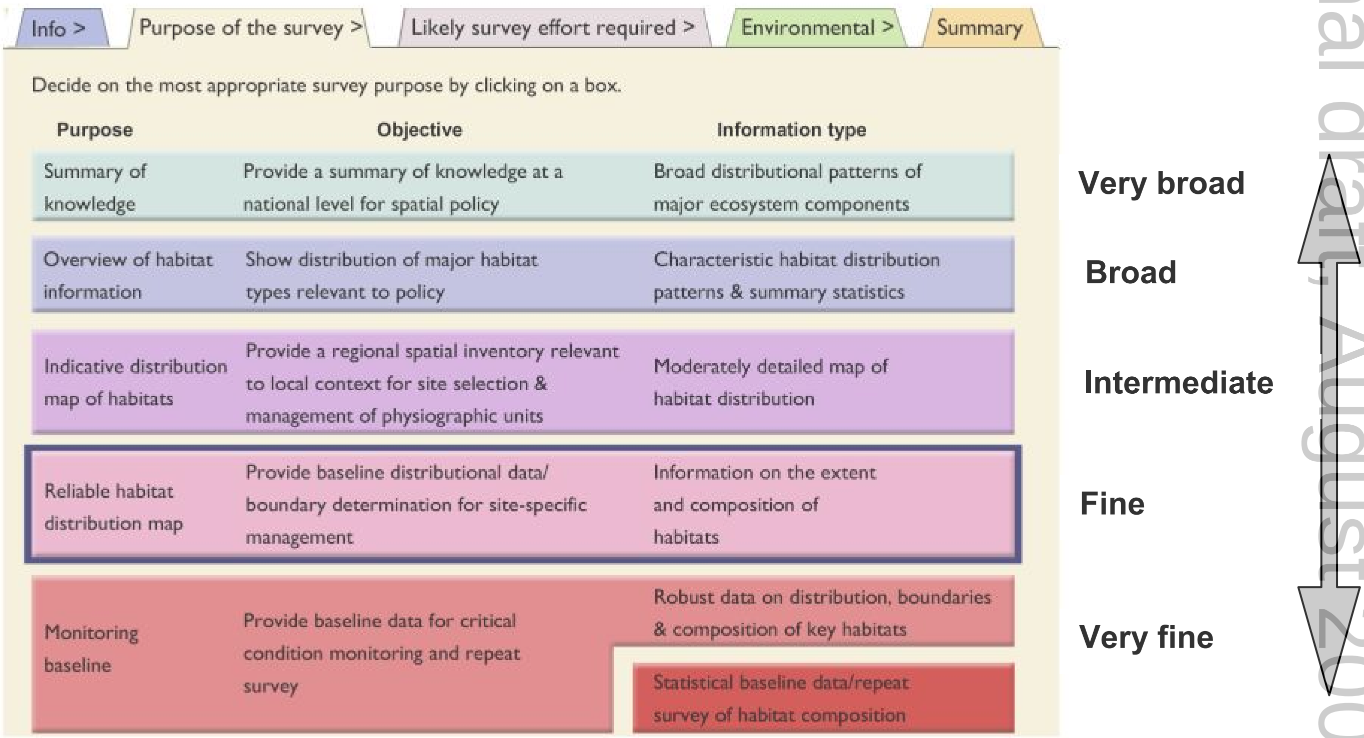
Illustration of the terms 'Site', 'Area' and 'Region' used in the MESH Guide to refer to different spatial areas (see text), here showing the Eastern Channel Regional Sea (as defined by MESH), and a number of Areas and Sites of different size. The four smallest Sites each have an extent of 2 x 2 km and their centres are 5 km apart.

The Scoping Tool

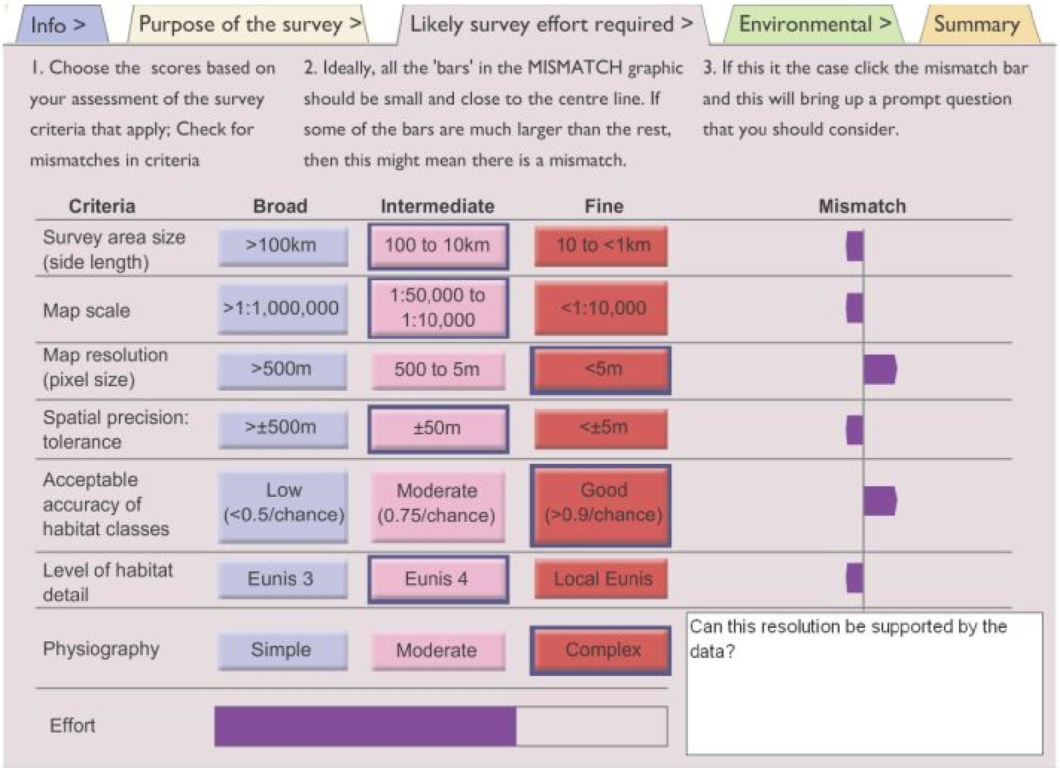
To help you scope the mapping programme, we provide an in interactive scoping tool in the form of a Flash® animation in the file Scoping Tool.swf. This tool should be used separately for each element of the mapping programme (broad, intermediate and fine scale) and to help you compile The Scoping Report.

This scoping tool guides you through a series of prompts asking you to consider the purpose of the survey, factors that will affect the amount of survey effort required and how different survey and environmental conditions will affect the suitability of various survey tools that may be available. A summary table highlights one or more potential survey strategies and provides a guidance comment based on an analysis of the choices you have made. The aim is to ensure that each element of the mapping programme is properly balanced and you are not anticipating too much or too little from the map or the data the survey might provide. If a mismatch is apparent, you can go back and try out various different scenarios.



The first section examines the overall scope of the survey and how the purpose, objectives and type of information required. This covers the range of scales seen in the figure *Mapping scale and purpose* in the section Scope the mapping programme.

The second section considers criteria about the mapping exercise that affect the likely survey effort required. If the criteria you select are not well matched, this will be shown in the mismatch graph and you will be prompted to consider a question relevant to the mismatch issue and possibly revise your selection. An indication of the relative survey effort required is given by the progression of the blue bar at the base of the sheet.



When considering mapping scale and mapping resolution, it helps to understand the concepts by imagining fixed, printed maps for the first (mapping scale), and ‘zoomable’ electronic maps for the second (mapping resolution).

The ‘map scale’ refers to the scale of a printed map (or fixed image). Here, you should select a scale that is appropriate to display the type of information selected under the previous section ‘Purpose of the Survey’. The table ‘Mapping Scale *vs* Real Dimensions’ shows how many metres on the ground are represented by one millimetre on a paper map, over a variety of mapping scales.

Mapping Scale *vs* Real Dimensions	
Map scale	**1mm on the map represents**
1:1,000	1 m
1:5,000	5 m
1:10,000	10 m
1:50,000	50 m
1:100,000	100 m
1:500,000	500 m
1:1,000,000	1 km

There is a cartographical limitation relating to the smallest feature that it is reasonable to display in print, as it is not practical to draw (or read) any feature that occupies less than ~9mm^2 on the printed map; that is a 3 x 3 mm square. Consequently, this is known as the Smallest Cartographical Unit (SCU). In selecting a map scale you need to consider the smallest feature you wish to represent. For intermediate scale maps this may be a small island or drying rock, say 150 m across. With an SCU of 3 x 3 mm, each millimetre on the map would represent 50 metres on the ground, so a suitable mapping scale would be 1:50,000. If you wanted a fine-scale map that showed features like mussel beds just 20 m across, you would need a scale at least 20 ÷ 3 x 1000 = 1:6,600 (i.e. < 1:10,000). However, if you were doing a broadscale summary and plotting presence/absence of a species in 10 km^2 units, then a scale of 1:1,000,000 would be suitable (1 cm = 10 km).

When considering map resolution, think about electronic zoomable maps and the real-world dimension that you want to represent by each pixel on a raster map. As you zoom into an electronic raster map, the pixel gets bigger, as you zoom out it gets smaller; BUT the real-world size represented by that pixel does not change. If you chose that each pixel would represent 10 metres on the ground, it doesn't matter how far you zoom into the image, you would never be able to resolve features that are less than 10 metres across. Normally, like any image made from pixels, you need several adjacent pixels to be similar before you can detect a pattern that may represent a feature (as in old, grainy newspaper photographs). Therefore, as a general 'rule-of-thumb' finescale, detailed mapping requires each pixel to represent <5 m on the ground, and a group of ten or more pixels may begin to show a feature (see also *What is habitat mapping?*). In broadscale mapping each pixel usually represents more than 500 m on the ground.

It is important to appreciate scale and resolution as separate concepts, but also to understand how they are inter-related. In electronic raster maps, resolution is independent of the scale. Because you can zoom in and out of the pixels the map scale will change, but the resolution will not. However, as soon as you print a map, you fix the pixel size on the paper printout and this fixes both the map resolution and the map scale. Imagine you have set our electronic map so that each pixel represents 5 metres on the ground. If you print that map so that each pixel covers 0.5 mm of paper, then 1 mm on paper will represent 10 metres on the ground, and the scale of the printed map will be 1:10,000. However, if you print the map so that each pixel covers 1 mm of paper, then each millimetre on paper will represent 5m on the ground and the scale of the printed map will be 1:5,000. Both maps have the same resolution.

If a cartographer now interprets a raster map by drawing around features to produce a vector map, the resolution of the vector map will depend either on the map scale or on the pixel size. If the pixels are smaller than the Smallest Cartographical Unit, the cartographer can draw around several pixels, but cannot draw anything smaller than the SCU. In this case, the resolution of the vector map is limited by the map scale. However, if the pixels are larger than the SCU, the cartographer cannot draw anything smaller than a single pixel, so the resolution of the vector map is limited by the pixel size.

After map scale and resolution you are asked to consider spatial precision (tolerance). This means how precisely do you want to place a feature on the map. Is it important to be very accurate and map the feature to within 5 metres of its actual position? This is relatively easy nowadays for shore-based surveys using differential Global Positioning Systems (dGPS), but can be difficult to achieve where data has been collected by instruments towed behind a boat (e.g. sidescan, video sledges) where the dGPS on the vessel, not the gear. Here, position is estimated by trigonometric calculation (‘layback’) or factoring in an offset determined from acoustic beacons attached to the towed gear. Historic data rarely has the spatial precision of data collected by modern survey; at worst the position has been estimated by ‘dead reckoning’. If you specify a high spatial precision you may preclude the use of a lot of (valuable) data where the spatial precision is not certain. The choice of spatial precision must reflect the mapping purpose; obviously it is excess to requirement to have pinpoint accuracy on a broadscale map.

The next item that affects survey effort is the acceptable accuracy of the habitat classes to be shown on the map. This has nothing to do with positional accuracy, but can be thought of as the accuracy of the habitat legend on the map. Do you want a singe colour (class) on the map to represent a single habitat that is known to be present, or could it represent two or more habitats that are equally likely to occur in that area? This desired classification accuracy influences the balance of effort between direct mapping of an area through field observation or sampling, and habitat modelling, where one can predict the presence of habitats based on proxies such as sediment type, depth, salinity etc, and knowing which habitats are likely to occur under which set of conditions. It also relates to the number of samples you might have to take and the effort put in to delineate distinct habitats. If you take samples along a 1 km long stretch of sandy beach and find that the habitat gradually changes from A to B, is it better to map it as a single area and say the habitat grades from A to B or is it better try and map it as two areas and say Habitat A occurs only in one portion and Habitat B only in the other?

In the scoping tool, the choices are expressed in terms of the probability that the assigned habitat classes are correct, with 0.5/chance being a 50% chance (1-in-2). Finescale surveys usually need a high degree of classification accuracy and may target habitats that are particularly sensitive to change. Such classification accuracy may be needed on a site-specific basis to assess the impacts of a local activity or over more extensive Regions to assess the impacts of global climate change. More usually, mapping over larger Regional extents relies heavily on habitat modelling, and it is acceptable that there is about a 50% chance that the habitat assigned by the model is correct. Considering there may be hundreds of habitats in a model, a 0.5/chance of predicting the right one represents quite good odds. To put this in perspective, the odds of throwing a 6 on one roll of a dice is 1/6 = 0.167/chance (16.7%).

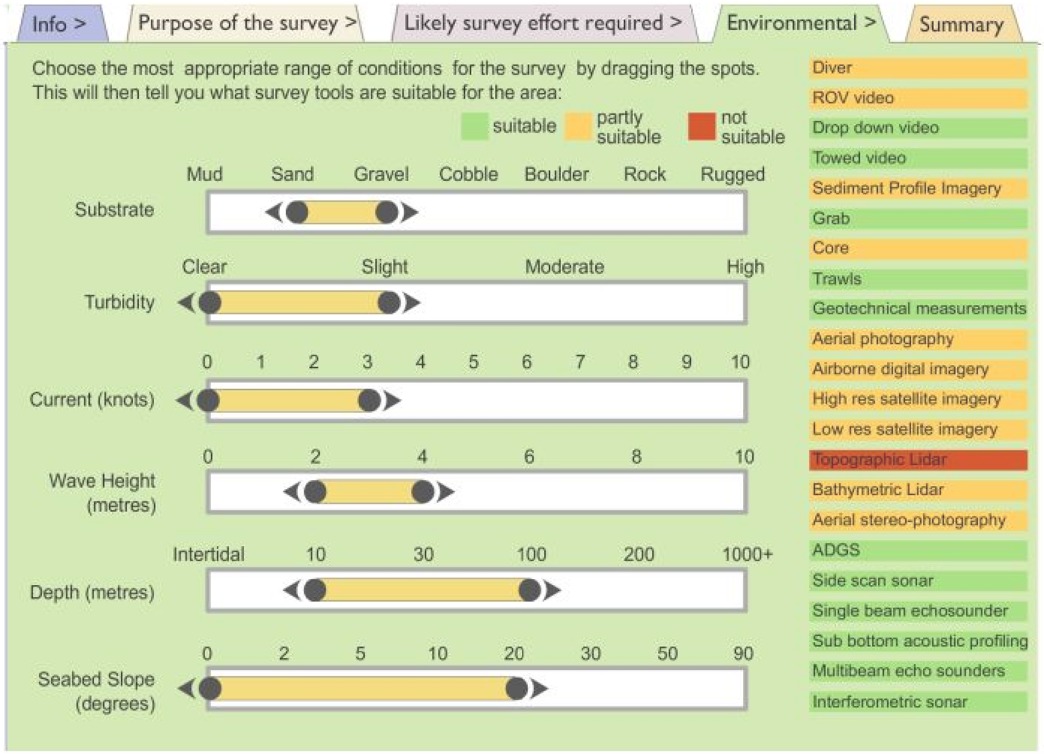
This classification accuracy is separate to considerations of the level of habitat detail required to meet the needs of the end user. As has been explained previously, EUNIS is a hierarchical classification system that adds habitat detail at each progressive stage of the hierarchy. EUNIS Level 3 is based purely on physical characteristics and the concept of biological zones ('littoral', 'circalittoral' etc). References to specific taxa are first introduced at Level 4, where major epifaunal taxa are used to discriminate hard substrate habitats. However, for softer substrates, discrimination is still based on the 'physical' and zonal attributes. See the table 'EUNIS Levels 3, 4 & 5 examples'. At Level 5, discrimination is based on both physical and biological characteristics of the habitats and often includes named species.

EUNIS Levels 3, 4 & 5 examples

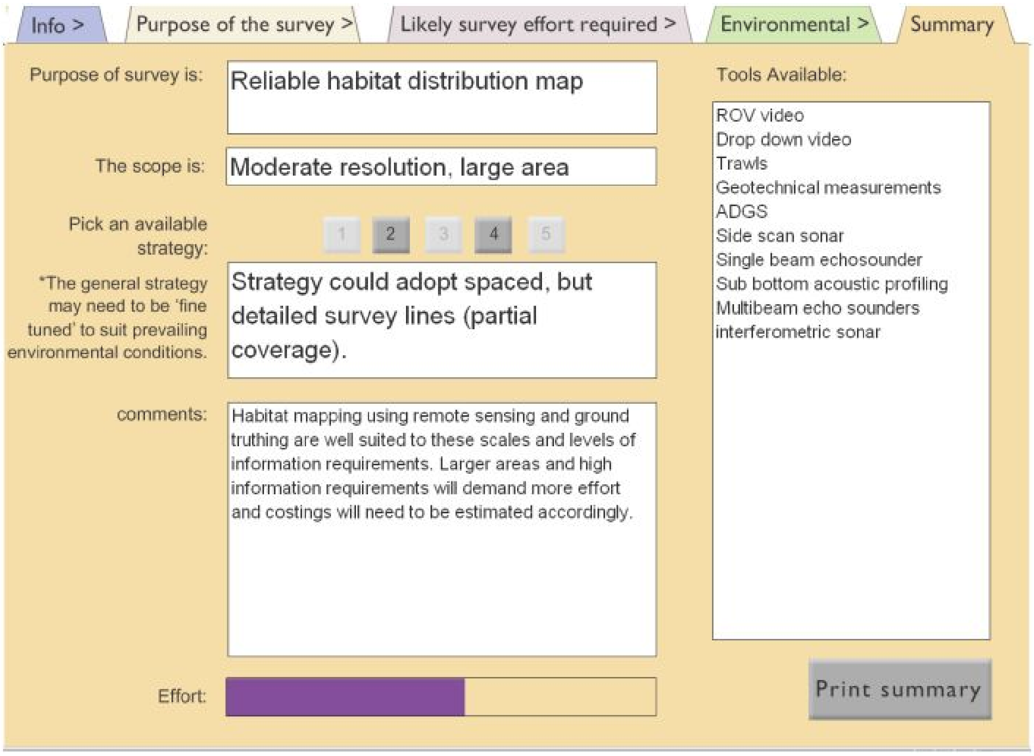
	Level	EUNIS Code	Habitat Description
Example 1	Level 3	A1.1	High-energy littoral rock
	Level 4	A1.11	Mytilus edulis and/or barnacle communities
	Level 5	A1.112	*Chthamalus* spp. on exposed upper eulittoral rock
Example 2	Level 3	A5.4	Sublittoral mixed sediments
	Level 4	A5.44	Circalittoral mixed sediments
	Level 5	A5.441	*Cerianthus lloydii* and other burrowing anemones in circalittoral muddy mixed sediment.

The options in the scoping tools are for EUNIS Level 3 or 4, or a 'Local Eunis' level. The latter means a EUNIS type classification derived from the data collected from samples (bottom-up classification), rather than imposing an existing EUNIS class (top-down classification). The choice should really reflect whether the habitat classes will be based on physical data only ('Eunis 3'), on physical and biological data (Eunis 4), or on a Eunis style classification based on physical and biological data derived from a sampling program ('Local Eunis'). The difference between this choice and the previous one relating to classification accuracy is that here you are selecting a minimum information content for the habitat classes, not a probability that the assigned classes will be right or wrong. Clearly the two are related, as there is a greater probability of correctly assigning a generalised habitat class such as 'High-energy littoral rock' than there is of a finer detailed class such as '*Mytilus edulis* and/or barnacle communities'.

The last choice on this sheet is termed 'Physiography'. This relates to the nature of the seabed that will be depicted through the map. If the actual seabed is highly variable, the physiography will be complex, and if you wan to represent it as such, select 'Complex'. However, if you only wish to represent it in a much simplified way, select 'Simple'. Foreknowledge of the area to be surveyed and the aims and objectives of the programme will be useful in making this selection, For example, a map of an area that is geologically variable and has high topographic relief would be considered complex and so require a lot of survey effort but an expansive area of flat sandy substrate would be regarded as ‘simple’.



The third section in the tool asks you to consider the environmental and other conditions likely to be met during the survey. Adjusting the slide bars will show how these conditions are likely to affect the suitability of a range of survey tools and techniques. This is discussed in more detail under the section Suitability of survey tools.



The last section summarises your choices, giving the purpose and scope of the survey and list the tools that are most suitable. It offers one or more strategy options to chose and indicates a relative level of survey effort associated with the selected strategy. Summary comments provide helpful hints about how you might proceed. There is an option to print out the summary page.

The tool is not intended to provide a definitive answer, but to help guide your thought-processes when considering the scope of the mapping programme and what can be realistically achieved within each of the broad, intermediate and fine scale elements. It can be used to promote focused discussion during consultation and to try out a number of potential scenarios.

Links to sections

What is habitat mapping?

Links to this section

Scoping Tool

The Scoping Report

Scope the mapping programme

Suitability of survey tools

Link to resources

ScopingTool\Scoping Report pro forma.doc

The Scoping Report

A suggested structure for the full Scoping Report is illustrated in the example below. This should be complemented by the printouts from the Scoping Tool, one for each element of the mapping programme.

You should complete the Scoping Report as you work through the scoping process, to capture the purpose and objectives of the overall programme and each element within it. The report sets the framework for the programme and provides relevant information for all those who will be involved in planning and executing the work.

Scoping Report
Purpose of the Programme (what will it aim to do?):
To provide a suite of habitat maps at different spatial scales in an offshore area of the eastern English Channel.
Objective of the Programme (why is it needed?):
To inform regional management policy relating to the conservation and sustainable use of marine resources.

Scoping Report

Background information:

New aggregate resources have been identified in an offshore area of the Eastern English Channel. The extraction of such resources is regulated under license. Studies of the area are required to inform the regulatory process.

Broadscale element

Purpose:

To show the distribution of major habitats over a broad scale area of the eastern English Channel containing the potential license areas.

Objective:

To provide a wider spatial & ecological context for intermediate and fine-scale studies.

Information type:

Habitat distribution patterns.

Criteria for map

Survey area	5000 sq km
Map scale:	1:1,000,000
Map resolution (pixel size):	1 km
Spatial precision:	+/- 500 m
Accuracy of habitat classes:	Low
Level of habitat detail	EUNIS Levels 3 & 4

Environment & Circumstances:

Fully saline. Moderate-strong tidal currents. Moderate turbidity. 20-70 m depth. Crosses major shipping separation zones (restricted movements). Some areas fished by trawlers & static gear.

Intermediate element

Purpose:

To indicate the distribution of habitats within and immediately around the cluster of 11 potential license areas.

Objective:

To provide a regional spatial inventory of habitats to complement the Regional Environmental Assessment (REA)

Information type:

Inventory and distribution of habitats.

Criteria for map

Survey area	1000 sq km
Map scale:	1:25,000
Map resolution (pixel size):	50 m
Spatial precision:	+/- 50 m
Accuracy of habitat classes:	Moderate
Level of habitat detail	EUNIS Levels 4 & 5

Environment & Circumstances:

Fully saline. Moderate-strong tidal currents. Moderate turbidity. 40-60 m depth. Crosses major shipping separation zones (restricted movements). Some areas fished by trawlers & static gear.

Scoping Report

Finescale element

Purpose:

To show detailed distribution of habitats within one of the potential license areas.

Objective:

To provide a baseline study in support of an Environmental Impact Assessment and future monitoring programme for this license area.

Information type:

Distribution, boundaries and composition of key habitats.

Criteria for map

Survey area	50 sq km
Map scale:	1:5,000
Map resolution (pixel size):	5 m
Spatial precision:	+/- 5 m
Accuracy of habitat classes:	High
Level of habitat detail	EUNIS Level 5

Environment & Circumstances:

Fully saline. Moderate-strong tidal currents. Moderate turbidity. 40-60 m depth. Borders traffic separation zone. Fished by trawlers.

Example of a MESH Scoping Report

A pro-forma for this Scoping Report and four worked examples are included in the Resources section as separate files:

Scoping Report pro forma.doc

Scoping Report_Demo1.doc

Scoping Report_Demo2.doc

Scoping Report_Demo3.doc

Scoping Report_Demo4.doc

Once the scoping phase of the planning process has been completed, all the consulted parties should have a clear understanding of:

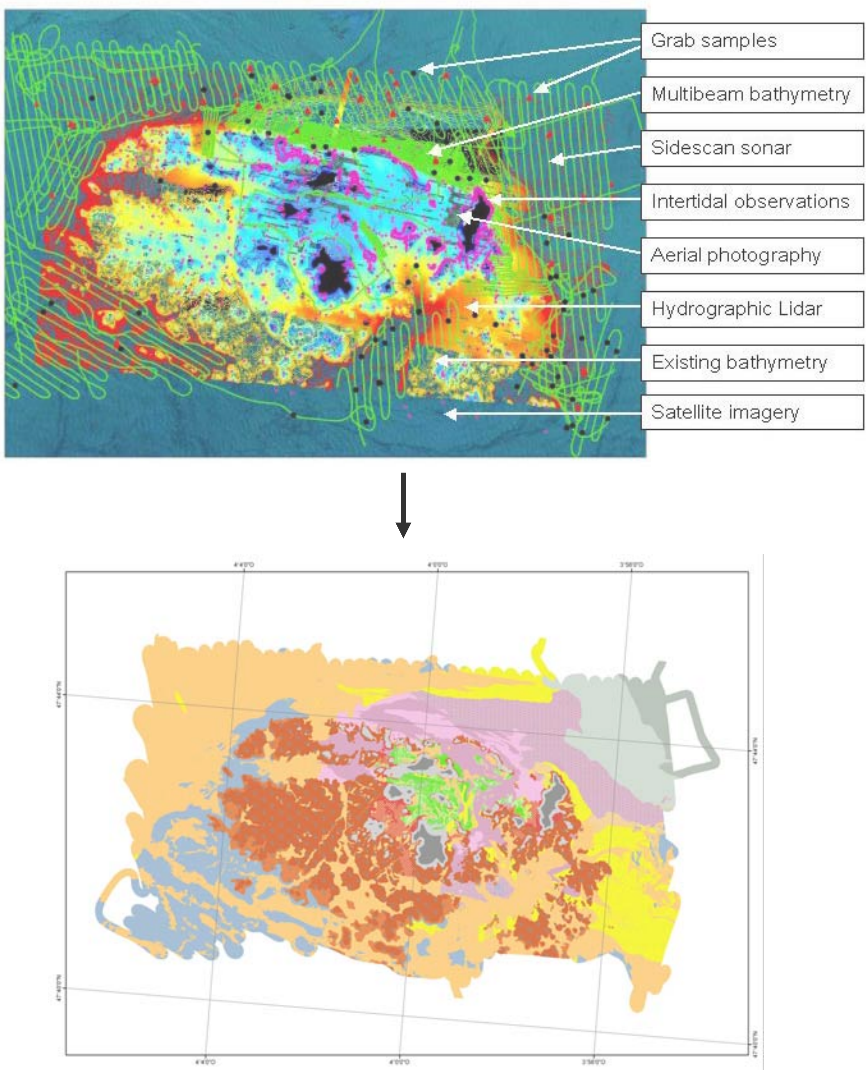
- the purpose and objectives of the overall programme.
- the type of information needed by the end-users of the maps.
- any need to split the programme into separate related elements to provide different information content.
- the precise information content required in each element of the programme.
- the specific mapping criteria for each element of the programme.

Once these things are established, the planning process can move on to consider which parts of the information and data can be sourced from existing studies, and which will require new surveys proceed. This is covered in the next section Determine the Information Gaps.

Determine the Information Gaps

The scoping exercise will have given an indication of the types of information that the maps need to convey. The next step in the planning process is to assess what data are needed to provide that information and whether such data already exist to an adequate standard. Data that are missing or fail to meet the required standard will need to be collected through new surveys and/or generated from models. The thoroughness of this gap analysis can therefore be crucial in determining the overall cost of the mapping programme and the confidence that can be placed in the final mapped outputs.

Habitat maps are a composite interpretation of many different kinds of data, some of which may be actual measurements or observations, while others may be derived from a model (e.g. tidal predictions).



Example of multiple data layers used in preparing a map of the Glénan archipelago, Brittany.

The data-needs of the project will be driven primarily by the criteria used to discriminate between habitats, such as salinity, type of sediment and the species present. Not all classifications schemes use the same criteria, so the data-needs of the relevant scheme should be understood at the outset. Hierarchical classification schemes, like EUNIS, use different criteria at different levels of the hierarchy, so some data sets will be fundamental to all levels of the hierarchy (e.g. for generalised broadscale mapping), while others will only be needed at the higher levels (for fine scale mapping).

The Gap Analysis is a desk-study and should critically assess the availability, quality, coverage and compatibility of existing data sets, as there is great risk to the integrity of the map if any of these factors is mistakenly assumed to be adequate. This assessment is assisted by modern metadata catalogues, such as that provided by the MESH project, which detail what, when, where, how and why the data were collected, and importantly, who owns it.

Some existing maps may be suitable as proxies for certain types of information, but checks should be made to understand the limitations of applying these interpretations of historic data to construct new habitat maps. Historical data sets should themselves be closely scrutinised to ensure they meet the needs of the current mapping project; if not, the data may need some form of manipulation, translation or truncation before it can be used.

The MESH Guide gives further in-depth consideration to these points and provides a checklist summary table to record the outcome of your analysis. This will highlight the data gaps, indicating what data need to be collected through new surveys or derived through modelling.

Links to other topics in the current section:

More information is provided in the current section about the process and outputs of The Gap Analysis. When the gap analysis has been completed, move onto the following section dealing with how to Specify new survey work

The Gap Analysis

The objective of the Gap Analysis is to identify which of the data needs of the project can be met by existing data and which will have to be collected through new surveys. Purchasing data or acquiring it through new surveys can both incur significant costs, so the Gap Analysis can be a critical step in establishing the magnitude of the budget required by a mapping programme.

The first stage is to consider *in detail* the question ‘What types of data are needed?’, as the answers are by no means always simple or clear-cut. If you are preparing a map according to an existing habitat classification scheme you must fully understand how that scheme works in order to identify the data types needed to apply the scheme. Different schemes describe and characterise habitats in different ways and may use different types of data or information. Some of the criteria used to discriminate between habitat classes may not be directly measurable, such as the level of exposure on a shore (e.g. ‘moderately exposed’ or ‘sheltered’) or the biological zonation (e.g. sublittoral, infralittoral, circalittoral). Other criteria, such as sediment type, may be expressed in rather general terms (e.g. ‘coarse sediment’) and so not require some of the expensive detailed analyses that may be routine outside the context of habitat mapping. In several hierarchical classification systems, such as EUNIS or the UK’s BioMar system (Connor *et al.*, 2004), the first few levels of the classification relate entirely to physical characteristics, so detailed species inventories may not be needed if the full hierarchy is not to be used. *What is habitat mapping?* provides further information on and the specific data needs of the EUNIS system are considered further in the section What data does EUNIS use? later in this section. If you are not required to use this 'top-down approach' of imposing an existing classification scheme, you will need to consider the range and quality of data that you will need to follow the empirical 'bottom-up' approach to differentiating and classifying habitats.

The second stage of the gap analysis is to search for existing data that meet your requirements. Points to consider here include availability, quality, and coverage. Just because data exist does not mean to say they are always readily accessible, so online data catalogues are a useful way to start investigating data availability; who owns it, how it can be accessed and at what cost. Metadata catalogues can also provide some indication of whether the data quality is likely to meet the needs of your mapping programme, as the records usually state explicitly if data has been collected to a national or international data standard. If not, you may be able to acquire a sample of the data so you can perform your own quality checks.

Where multiple data sets are used, you should also consider issues of data compatibility, as different data sets may have been collected using different instruments or different standards and protocols. It is common for taxonomic nomenclature to vary somewhat between different biological data sets, so checks need to be made for pseudonyms and to establish if species lists can be merged directly of will need some form of translation or truncation to a higher taxonomic level before they can be harmonised. You may be forced to reject available data on the grounds that it does not meet that quality standard required or is not compatible with other data sets that you *are* able to use. Such rejections will highlight gaps in the available data that must be filled by new surveys or data modelling.

Given that the data is of suitable quality for use in the study, you must also determine how well it covers the area you wish to map. Data coverage should assess both the spatial extent and density of the available data and this can frequently be visualised by plotting the available data layers and/or survey lines and sampling points in a GIS. Clearly, where the geographic bounds of the existing surveys do not cover the whole of the area to be mapped, there is a data gap (an absence) that must be filled. However, within the existing surveys, there may be insufficient density of data to suit the needs of the map; the sampling points or survey lines may be too far apart to allow the map to be drawn at the required resolution, in which case additional sample points or survey lines may be needed.

The gap analysis should pay specific attention to the inherent limitations of using interpreted data layers such as a map of seabed sediments (see the section on data limitations). These interpretations may be useful proxies for habitat mapping studies, but it is important to understand the nature of the underlying data and the purpose of the initial interpretation as these rarely match the precise needs of habitat mapping. Existing maps may be the best information available, so they should not be dismissed out of hand but used with appropriate caution. The gap analysis should examine the quality and provenance of existing data interpretations and assess their suitability for use in the mapping programme.

The final stage of the gap analysis is to produce a report capturing the essential information for the benefit of all involved in the planning and execution of the project. The report should systematically cover each element of the mapping programme (broad, intermediate and fine scale) and will benefit greatly from the inclusion of a GIS project or workspace showing the available metadata (and data or interpreted layers, if available). The format of the report is likely to be project specific and should be quite detailed. A rapid overview of the Gap Analysis and an '*aide memoire*' can be provided in tabular form, as illustrated here in a worked example of the Gap Analysis Summary Table (also provided in the Resources section as Gap analysis pro forma.doc Some details of the mapping area are followed by a table listing a variety of data types commonly used in mapping studies. The table is completed to show which of these will be required and whether existing data sets are available (in full or in part) to a suitable quality standard and density of coverage. Where partial data or no data are available, an assessment is made as to whether the data gaps are best filled by new surveys or by data modelling.

Gap Analysis Summary for: Area X, English Channel

Details of mapping area: 10 x 15 km. Depth range 20 to 70 m. Fully saline. Unconsolidated sediments, possible rock outcrops. Existing seabed sediment and solid geology maps available. Some digital bathymetry available from single beam surveys.

Data Types	Required	Available	Is the data of suitable…		Are new data needed?	
			Quality?	Coverage?	From survey	From model
Elevation						
Topography (heights)	No					
Bathymetry (depths)	Yes	Part	OK	No	Part	
Slope	Yes	No				Yes
Geological						
Lithology	Yes	All	OK	Yes		
Sediment thickness	No					
Sediment/substrate types	Yes	Part	OK	No	Part	
Bedforms	Yes	Part			Part	Part
Granulometry (PSA)	Yes	No			Yes	
Geotechnical properties	No					
Biological						
Infauna	Yes	Yes	Rejected		Yes	
Epifauna &/or Epiflora	Yes	Part	OK	Poor	Yes	
Structural fauna (reefs)	Yes	No			Yes	
Physical/Oceanographic						
Temperature	No					
Light penetration	No					

Wave exposure	No					
Salinity	Yes	Model	OK	OK		
Wave base	Yes	Model	OK	OK		
Tides/currents	Yes	Model	OK	OK		
Seabed shear stress	Yes	Model	OK	No	Yes	Yes
Turbidity	Yes	Model	OK	OK		

Example of a table summarising the output from a desk study and gap analysis of the availability and suitability of data relevant to mapping a hypothetical area in the English Channel

The Glenan Archipelago Case Study presents details of a shallow-water mapping project on the coast of Brittany, in France. Section 2 of this document Glenan Archipelago Case Study.pdf provides and example of the process of collating and assessing existing data layers to identify data gaps that need to be filled by new surveys.

Links to further sections dealing with Gap Analyis:

What data does EUNIS use?; Data availability; Data quality; Data compatibility; Data coverage; Data limitations.

Links to other sections in the MESH Guide:

What is habitat mapping? - section What classification schemes are available?

Links to other topics in the current section:

Scoping Tool

Determine the Information Gaps

The Gap Analysis

Specify new survey work

data availability

data quality

data compatibility

Data coverage

data limitations

Links to resources

Scoping Report pro forma.doc

Scoping Report_Demo1.doc

Scoping Report_Demo2.doc

Scoping Report_Demo3.doc

Scoping Report_Demo4.doc

Gap analysis pro forma.doc

Glenan Archipelago Case Study.pdf

What data does EUNIS use?

The EUNIS classification system uses a variety of criteria to characterise and discriminate between habitat types. In order to appreciate the answer to the question ‘What data does the EUNIS use?’ it is first to understand two basic fundamental of the EUNIS system.

1. The EUNIS system covers both terrestrial and marine habitats, and labels them with an alphanumeric code such as ‘A3.54’. All marine habitats fall under the code letter ‘A’, with letters B to J being reserved for various types of terrestrial habitat. The marine habitats are spit into eight types, ‘A1’ to ‘A8’. There are six hierarchical classification levels for marine habitats with ‘A’ being level 1, A1-A8 being level 2 etc, so a code of ‘A3.54’ would represent level 4 (four characters in the alphanumeric code).

2. For marine habitats, the EUNIS system uses its own criteria to characterise and discriminate habitats down to level 4, but beyond this (levels 5 & 6) the criteria are drawn from other classification systems and combine these in the common framework. Prominent of these other systems is the Marine Habitat Classification for Britain and Ireland, version 04.05 (Connor *et al.*, 2004), also known as the ‘MNCR BioMar classification’. Systems relating to the Baltic and Mediterranean were also used, but are not as relevant to the geographical area covered by MESH.

Hence, to answer the question ‘What data does EUNIS use?’ we have to refer the reader to both the EUNIS and the BioMar classification systems.

Connor *et al.* (2004) neatly summarise the typical characteristics used in discriminating and defining habitat types as “salinity, wave exposure, tidal currents, substratum, zone, height or depth band and, where appropriate, other factors critical to that particular type” and further explain that “for the rocky habitats, biotopes are shown in relation to energy levels, whereas for sediment habitats, biotopes are shown in relation to sediment type using a modified Folk triangle approach (Folk 1954)”. Biological discriminants range from characteristic life forms (e.g. hydroid turfs, kelp park) to “a list of those species which contribute most to the overall similarity between core records assigned to the type, i.e. characterise the type, with associated information on their frequency of occurrence, their individual contribution to the similarity within the core data set of records, and the typical abundance at which they occur’”

How these characteristics, and others, are applied in EUNIS levels 1 to 4 can be seen in the keys to the EUNIS marine classification presented on pages 13 to 27 of the document EUNIS Habitat Classification Revised 2004.pdf.

For a basic understanding of the data used by EUNIS, and the reasons it is used we recommend the reader refers to three brief tables in Connor *et al.* 2004 (included in the Resource section as MNCR_04_05_introduction.pdf)

- Table 1 Environmental factors which influence community structure’ (pages 13 to15),

- Table 4 Rationale behind the main divisions adopted in the primary habitat matrix (EUNIS levels 2 and 3) (pages 23 & 24)
- Table 5 Marine biological zones and the factors determining them (page 25)

For a fuller understanding, it is recommended these two documents are read more thoroughly, along with the section from *What is habitat mapping?* entitled 'What classification schemes are available?'.

Data availability

There are numerous on-line catalogues or inventories that can be used to search for existing data sets relevant to European marine studies. Some examples are given below, but the list is not comprehensive.

You should be aware that in Europe, accessing such data is not usually straight forward, as the intellectual property (IP) rights to the data may be owned by those who collected it. Data may be available for outright purchase, or access may be licensed on an annual basis. Frequently, restrictions are placed on the use of the data to protect the IP rights of the owner and ensure that the licensee does not pass on the data to third parties in its raw form or even as an interpreted layer. It is wise to examine very closely the conditions of use of any data that you intend to purchase, and to recognise that 'free' data may not provide any guarantee as to its quality. In all cases, however, information about the data sets (i.e. 'metadata) should be free to access.

We recommend starting with the MESH metadata catalogue of seabed mapping studies (http://www.searchmesh.net/metadata), which is the product of the MESH initiative to collate and harmonise existing habitat maps. This queryable database catalogue lists hundreds of mapping studies or data sets and is linked to the MESH webGIS mapping site (http://www.searchmesh.net/webGIS) where the maps and /or bounds of the data sets can be displayed.

The OceanNET web portal (http://www.oceannet.org/) provides access to three UK working groups operated by the Inter-Agency Committee on Marine Science and Technology (IACMST) that focus on advancing areas of marine science, namely the UK Global Ocean Observing System Action Group (GOOSAG), the Marine Environmental Data Action Group (MEDAG) and the Marine Data and Information Partnership (MDIP). The MDIP is establishing a network of Data Archive centres (DACs) to act as repositories for all UK related marine data; currently (2007) these comprise the British Oceanographic Data Centre (BODC) (http://www.bodc.ac.uk/), the United Kingdom Hydrographic Office (UKHO) (http://www.ukho.gov.uk/) and the Data Archive for Seabed Species and Habitats (DASSH) (http://www.dassh.ac.uk/).

At the European level, the European Commission support the Sea-Search website (http://www.sea-search.net/) which provides "a gateway to Oceanographic and Marine Data & Information in Europe" including European data centres, data networks, data sets and marine organisations

Specialist organisations may also provide catalogues of their own data (see examples from the British Geological Survey (http://www.bgs.ac.uk/data/home.html), Cefas (http://www.cefas.co.uk/data.htm), Ifremer (http://www.ifremer.fr/sismer/index_UK.htm) and ICES (http://www.ices.dk/datacentre/data_intro.asp)), as might specialist interest groups, such as the oil and aggregate industries.

Information about very broadscale data sets may be available through international organisations such as the Global Change Master Directory to Earth Science and services (http://gcmd.nasa.gov/KeywordSearch/Keywords.do?Portal=GCMD&KeywordPath=Parameters%7COCEANS&MetadataType=0&homepg) or the Intergovernmental Oceanographic Commission (http://ioc.unesco.org/) of UNESCO which hosts the International Oceanographic Data Information and Exchange (http://www.iode.org/), a worldwide service oriented network consisting of DNAs (Designated National Agencies), NODCs (National Oceanographic Data Centres), RNODCs (Responsible National Oceanographic Data Centres) and WDCs (World Data Centres – Oceanography). This site provides lists of national coordinators for oceanographic data management (http://www.iode.org/index.php?option=com_oe&task=viewGroupRecord&groupID=59&Itemid=42) and marine information management (http://www.iode.org/index.php?option=com_oe&task=viewGroupRecord&groupID=60&Itemid=43).

In some mapping programmes, the availability of **existing maps or modelled data** is of specific interest, either as raster images or vector data. Sediment type, bathymetry and bed stress ('water energy') are frequently required, so these are discussed briefly below.

Sediment maps are generally constructed based on the Folk classification system and are commonly published by national Geological Surveys or sometimes Hydrographic Offices or Universities. Some institutes such as the British Geological Survey are making their seabed sediment maps available digitally (http://www.bgs.ac.uk/products/digitalmaps/home.html) to allow them to be incorporated easily into Geographic Information Systems, with map purchases available on-line. Some maps may be (or become) outdated and a significant amount of new data might be available. Efforts should be made to assess the quality and utility of the interpreted sediment layer and the data it is based upon. The mapping of rocky substrata can frequently be inadequate in interpretations based largely on point sample data (grabs, corers). For modelling purposes, there is a greater need to work with the original quantitative sediment data rather than interpreted maps. Where original data exist, the choice of the variable used in modelling will largely depend on the extent and density of the data over the study area. For historic data sets, the original data may be lost and only univariate descriptors recorded, in which case the median grain size is likely to be the most frequently reported parameter.

Bathymetry datasets are generally available from the national Hydrographic Offices and usually the original soundings are available (at a fee). The resolution of the raw data may be variable, depending on the complexity of the seafloor. If data is needed over a larger area, several Hydrographic Offices may need to be contacted and compiling the data may become very complex as it may be held in various formats, referenced to different ellipsoids and different reference (datum) levels. Compiled bathymetry datasets are available (at cost), such as the General Bathymetric Chart of the Oceans (GEBCO) (http://www.bodc.ac.uk/products/bodc_products/gebco/) from the British Oceanographic Data Centre, or the British Geological Survey's vector based digital bathymetry of UK and adjacent European waters 'DigBath250' (http://www.bgs.ac.uk/products/digbath250/) (original soundings compiled to a 1:250 000 scale).

'Water Energy' data (i.e. near-bed stress, bottom current) is mostly obtained from institutes active in hydrodynamic and sediment transport modelling, such as the Proudman Oceanographic Laboratory (http://www.pol.ac.uk/). Some universities or private organisations working in this field may also have data available (see also the European Directory of Marine Organisations (http://www.sea-search.net/edmo/welcome.htm) on the Sea-Search website (http://www.sea-search.net/)

Data quality

The quality of existing data can be a major issue as, until recently, the need to record metadata has been largely overlooked. Historic data is often assumed to be correct, without any means of assessing whether or not it was collected, processed or interpreted adequately. Metadata (http://en.wikipedia.org/wiki/Metadata) is 'data about data' and records information about how the data were collected and/or processed, so is vital to the Quality Assurance (QA) of the data sets.

It is important to assess the quality of existing data before using it in a mapping programme, as it will have implications for the confidence that can be placed in the mapped output. Data quality should match or exceed the criteria stipulated in the scoping report. So, for example, if the positional accuracy (spatial precision) of the data is ±50 metres, it would be suitable for used in broad and intermediate scale maps, but not in fine scale maps.

For some data types there are recognised quality standards. Bathymetric data is covered by the International Hydrographic Organisation (IHO) standards for hydrographic surveys (IHO Special Order and Orders 1, 2 and 3) which give standards for positional and depth accuracy and data density. In a paper on international hydrographic survey standards, Mills (1998; resource file IHO survey standards.pdf gives a very instructive lay-mans summary on the meaning of confidence and source of error. This is reproduced below, as the general concepts are relevant to any consideration of data quality.

"A brief review of measurement errors is needed to understand the meaning of the 95% confidence levels specified for position and depth accuracies in the new Standards. An error is the difference between a measured value and the correct or true value and can be categorized as a blunder, systematic error or random error. Blunders are generally large errors caused by inattentiveness or lack of skill on the part of the observer. Systematic errors are those that follow some physical law or rule by which they can be predicted. Random errors are generally small errors resulting from the limitations of measuring devices and processes, are equally likely to be negative or positive, and are governed by the laws of probability. Blunders must be eliminated by the establishment of adequate "checking" procedures and are assumed to not be present in quality hydrographic survey data sets. Systematic errors are measured or modeled using calibration techniques and must be removed from survey data prior to evaluating them against the IHO. Random errors result from the inability to perfectly measure any quantity or to perfectly model any systematic error."

Quality standards exist for many types of data, and it is normal for professionals, academics and operators to be aware of the relevant standards in their field of work pertaining to the acquisitions, processing, analysis and recording of data, so **it is recommended to have a 'competent person' assess the quality of data sets**.

Sometimes, as standard does not exist, *per se*, such as in identifying biological taxa, so assessment of the quality of the data has to be made against other criteria, such as the inclusion of the processing laboratory in a recognised quality control scheme (e.g. the UK's National Marine Biological Analytical Quality Control scheme, or NMBAQC) or the recognised expertise of an individual by their peers.

As mapped data falls under the general description of 'geographical information' it is as well to be aware of the existence of the International Organization of Standardization (ISO) and specifically the ISO Technical Committee 211 (ISO/TC 211) which is dedicated to developing and deploying standards relating to Geographic information/ Geomatics. The ISO standards are known by their serial numbers, with the ISO 19100 series relating to geographic information. ISO19115 is the recently completed standard for geographic metadata, and is somewhat impenetrable to the layman or non-expert. Thankfully, the standard has often been interpreted by national bodies and presented in a simplified more user-friendly format for those who have to comply with it.

Data compatibility

Another factor that should be considered is the compatibility of existing data sets. Frequently, a data search may reveal multiple sources of similar data types, but the metadata may reveal that the individual data sets are not compatible, as the data have not been collected in a consistent manner among the different studies, as in the following hypothetical example.

Example: Study A and study B conducted sidescan acoustic surveys in adjacent areas. The metadata shows they used different systems, determined positional information in different ways and used different software to process the data. While both studies provided valuable outputs, Study A provided a high resolution image of the seabed with high positional accuracy, while study B was a lower resolution with lower accuracy. Therefore, the initial interpretations of these data are not likely to be entirely compatible, as one will show fine-scale features and the other will not.

One option here would be to harmonise the interpretations by re-interpreting the high-resolution data using only the feature categories identified in the low-resolution data (the converse can not be done). It may be desirable to re-process the original high-resolution data with the same software used on the original low-resolution data. Alternatively, if the map needs high-resolution data, Area B will have to be surveyed with the higher resolution system.

Metadata	Study A	Study B
Make & Model	Benthos SIS 1624	Edgetech 4200 FS1500
Operating frequency (kHz)	400	120
Tow speed (knots)	3	6
Altitude above seabed (m)	6	15
Position derived from	Acoustic tracking device	Layback calculation
Processing software	Caris	ISIS

Metadata relating to two hypothetical sidescan sonar surveys, illustrating potential incompatibility.

Care must be taken to assess the compatibility of similar data sets before they are combined or subject to some form of joint interpretation. Even where the metadata suggest that two data sets are compatible, the data itself should be carefully scrutinised to check for differences that may not be highlighted in the metadata. Different faunal data sets are particularly prone to taxonomic inconsistencies that need to be addressed before the data can be pooled. Two common inconsistencies arise due to changes in the taxonomic literature and differences in the precision to which taxa are identified.

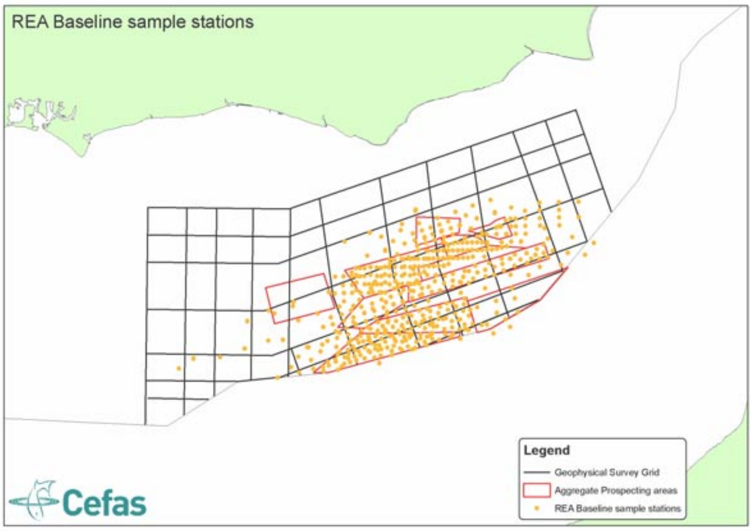
The general advice on this issue is to seek ways to harmonise existing data sets that are apparently incompatible, as this is likely to be more cost-efficient than starting afresh and collecting new data. The process will require some transformation or manipulation of the data to meet a common standard. Do not lose sight of the fact that the data needs to be ‘fit-for-purpose’, which in this case is habitat mapping, and that some standards, such as the IHO standards for hydrographic surveys, may far exceed your requirements.

Data coverage

The advent of Geographical Information Systems (GIS) has vastly improved our ability to rapidly assess the spatial coverage of the multiple data sets required to build a seabed habitat map. As part of the desk study and gap-analysis it is advisable to construct a GIS that will show the location and extent of the existing data, as this will highlight spatial gaps, both in terms of the geographical extent of the data and the density of coverage.

Plotting merely the bounds of existing surveys can give a misleading impression of the data coverage and density, so it is advised to plot the positions of actual sample points and survey lines as these will highlight areas where data density is poor.

The example here is taken from the planning stage of a habitat mapping project in the eastern English Channel (James *et al.*, 2007), covering an area of ~5,000 sq km. One of the principal aims of the study was to place an existing Regional Environmental Assessment (REA) of potential aggregate extraction areas into a wider spatial context. The intended survey grid is shown in relation to the location of point samples (yellow dots) taken in the REA and the aggregate prospecting areas (red polygons). The new study would clearly aim to focus sampling effort outside the central area.



Extract from a GIS used in a gap analysis of a mapping project in the eastern English Channel.

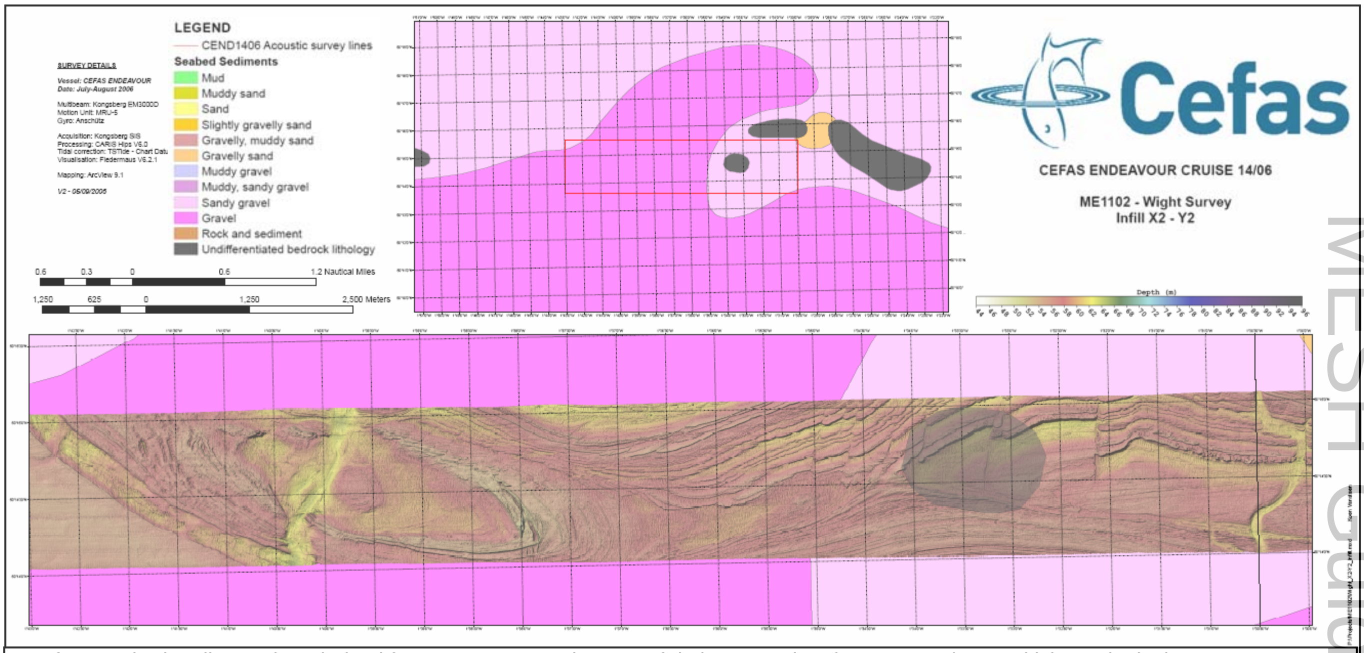
The GIS project or workspace will be a valuable asset for the later parts of the planning process that address survey strategies and design, so it should be supplied as part of the gap analysis report.

Data limitations

It is important for the gap analysis to recognise and highlight potential limitations in existing data and interpretations to ensure they are used appropriately. It is frequently tempting to accept interpretations that you think provide the information your need without appreciating how those interpretations have been derived and the nature of the studies on which they are based.

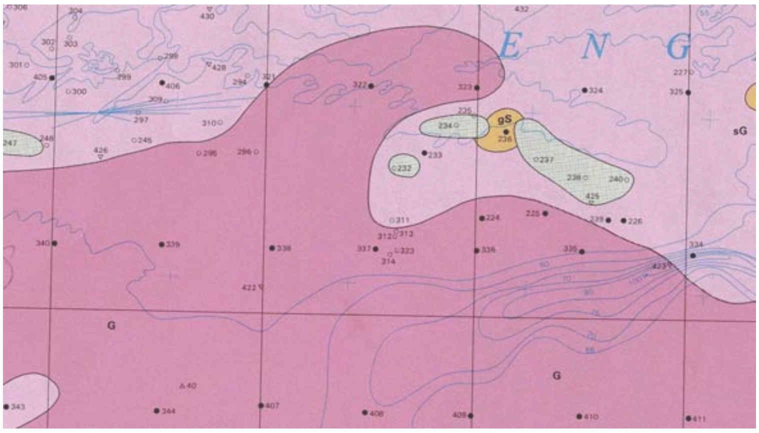
An example is given from an ongoing study in the central English Channel (Coggan, pers. comm.) to map the locations and extent of potential Annex I 'rocky reef' habitats, which includes rock outcrops and boulder/cobble reefs. In one of the areas targeted for survey, the seabed sediment chart indicated small, discrete areas of rock outcrop lying adjacent to an extensive gravel area. The study conducted a full coverage multibeam survey over part of this area (see diagram), which revealed it to be far more complex and varied than anticipated, with an extensive area of outcropping rock showing faulting and relict valley systems.

Re-examination of the seabed sediment chart showed the original sampling points lay largely outside the area covered by the acoustic survey. This highlighted the danger of using the interpretation in isolation from the dataset from which it was derived, including considering its vintage. Further information from the corresponding solid geology and Quaternary charts may also have been valuable as these often indicate how close the underlying rock is to the surface of the seabed.



© Cefas. Seabed sediment data derived from 1:250,000 scale BGS Digital Data under Licence 2005/067. British Geological Survey. © NERC

Multibeam image from the English Channel superimposed on a seabed sediment chart (bottom). The top image shows the location of the multibeam survey (red rectangle) relative to the wider seabed sediment information.



Extract from BGS 1:250,000 map illustrating PSA sample data positions used in drawing seabed sediment type boundaries.

The main advice here is to objectively examine existing data and interpretations so that you fully understand the limitations they have if/when you use them within your mapping programme.

Links to other sections in the MESH Guide

What is habitat mapping? – the section entitled 'What classification schemes are available'

Links to resources

EUNIS Habitat Classification Revised 2004.pdf

MNCR_04_05_introduction.pdf

IHO survey standards.pdf

Links to other websites

http://www.searchmesh.net/Default.aspx?page=1402

http://www.searchmesh.net/default.aspx?page=1546

http://www.oceannet.org/

http://www.bodc.ac.uk/

http://www.ukho.gov.uk/

http://www.dassh.ac.uk/

http://www.sea-search.net/

http://www.bgs.ac.uk/data/home.html

http://www.cefas.co.uk/data.htm

http://www.ifremer.fr/sismer/index_UK.htm

http://www.ices.dk/datacentre/data_intro.asp

http://gcmd.nasa.gov/KeywordSearch/Keywords.do?Portal=GCMD&KeywordPath=

http://ioc.unesco.org/

http://www.iode.org/

http://www.iode.org/index.php?option=com_oe&task=viewGroupRecord&groupID=59&Itemid=42

http://www.iode.org/index.php?option=com_oe&task=viewGroupRecord&groupID=60&Itemid=43

http://www.bgs.ac.uk/products/digitalmaps/home.html

http://www.bodc.ac.uk/products/bodc_products/gebco/

http://www.bgs.ac.uk/products/digbath250/

Proudman Oceanographic Laboratory

European Directory of Marine Organisations

http://www.sea-search.net/

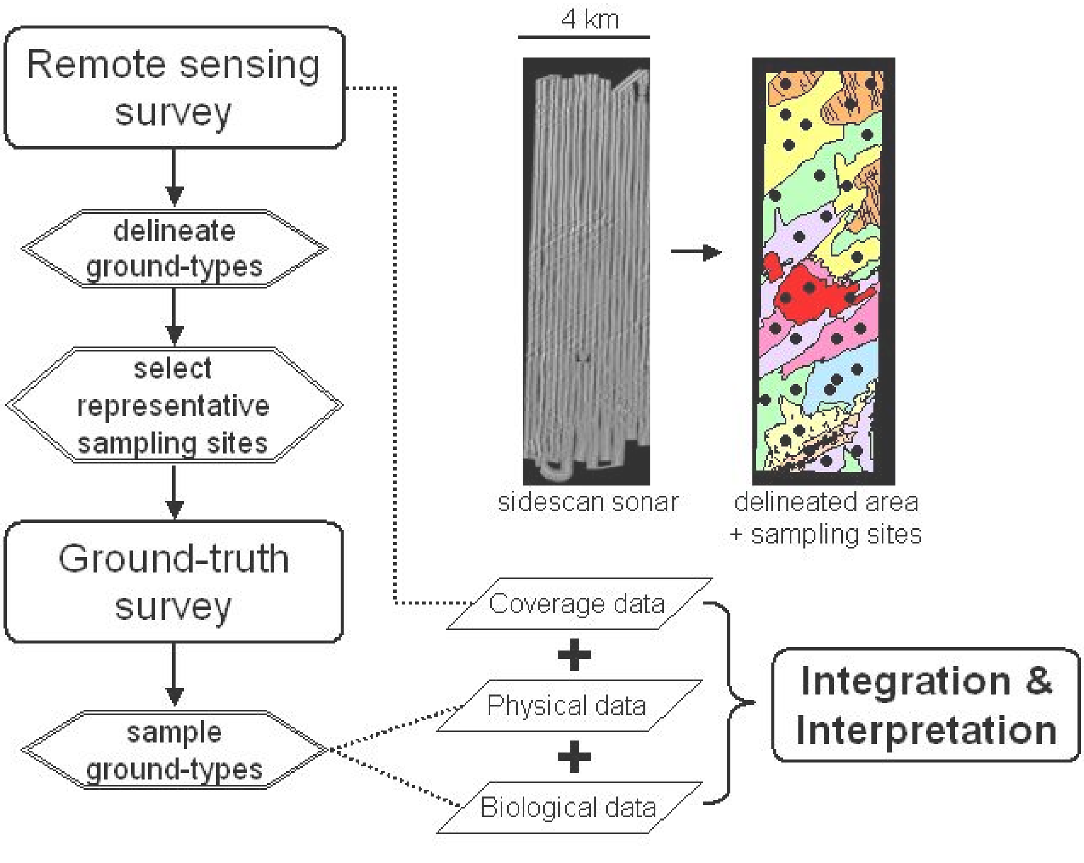
http://en.wikipedia.org/wiki/Metadata

http://www.nmbaqcs.org/

Specify new survey work

If the gap analysis has identified a need for data to be collected through new surveys, the next stage in the planning process is to draw up a survey specification that will meet those needs. This requires some knowledge of different survey strategies and the capabilities of the various sampling tools that are available.

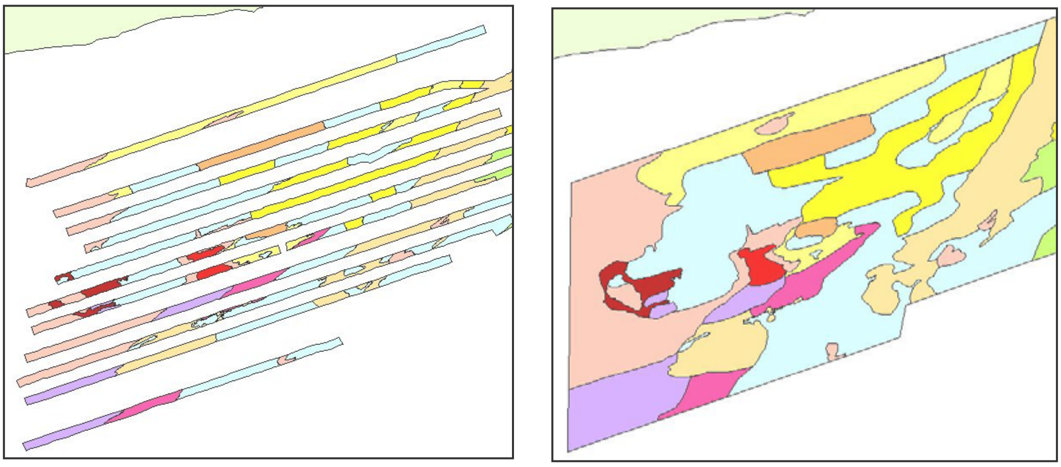
The general approach to surveying involves the use of remote sensing and direct sampling techniques. Remote sensing techniques provide coverage of an area of shore or seabed, but they do not (usually) detect habitats *per se*. Rather, they allow the area surveyed to be divided into a number of regions that represent different ground types. Direct sampling techniques typically supply physical and/or biological data from point samples, and it is these data that are needed to identify and classify the habitats. Habitat maps can be produced from direct sampling alone, but would require an intensive sampling programme to provide the spatial coverage necessary. Instead, it is more efficient and effective to use the two techniques in combination, targeting the direct sampling at different ground types. This provides both coverage and stratified ground-truth data that can subsequently be integrated and interpreted to produce a map. MESH recommends this basic strategy of remote sensing followed by directed ground-truth sampling to ensure representative sampling of the area to be mapped.



Simplified survey strategy. Data are acquired from remote surveys and directed ground-truth sampling, ready for input into the integration and interpretation phase of the mapping process.

Remote sensing and ground-truth surveys employ a range of different technologies, instruments and devices, some of which provide several different types of data (or sample), while others provide only one. Optical remote sensing techniques (e.g. satellite imagery, aerial photography and LiDAR) are effective on the shore and in clear shallow waters. Ship-based surveys use an array of acoustic techniques to image the seabed, with higher frequency systems like multibeam or sidescan sonar producing plan-images of the seabed surface while lower frequency systems (e.g. 'sub-bottom profilers') penetrate the seabed giving profile images of the sediment layers and rock strata. Shore-based ground-truth surveys tend to favour direct observation but ship-based surveys tend to rely heavily on sampling devices like grabs, trawls and remote observation (video & 'stills' cameras). How the surveys are approached will depend on the particular combination of tools and techniques that are selected (or available). We summarise the capabilities and limitations of a variety of generic sensing and sampling techniques and, through the interactive scoping tool, allow the user to see how their suitability changes under different survey conditions. Guidelines for operating the specific sampling tools are given in *How do I collect my data?*.

This stage of the planning process should outline the **survey strategy**; being a general plan of action required to meet the survey needs. This strategy should decide what type and how much remote sensing is needed. The rapidity of aerial survey techniques usually allows for full coverage of the shore and shallow intertidal areas, but the slower ship-based surveys are frequently constrained by time and cost such that a choice has to be made between a full coverage survey of a small area or a partial coverage survey of a larger area. As soon as the coverage falls below 100%, the ability to map at fine resolution is lost, but lower resolutions can be achieved to varying levels of confidence using interpolation techniques on partial coverage surveys. A 'nested' survey strategy combines partial coverage over a broad area with more detailed coverage targeting specific areas of interest.



Example of a partial coverage survey (left) with resulting interpolated map (right). The area surveyed is ~20 km wide

The strategy for ground-truth sampling will be influenced by the purpose of the map and the level of confidence required. There are options to take one or more ground-truth samples from every distinct area shown by the remote survey, or just every distinct ground type. There may also be a need to further stratify the sampling to account for recognised ecological zonations, such as the immersion/emersion cycle of intertidal areas, or depth/turbidity gradients in deeper waters.

The output of this planning process should be a **survey specification**, which should detail the survey objectives and outline the strategies and sequence of work. There should be sufficient detail to allow those who are proposing the survey to estimate the likely cost, such that they can bid for funds or put the work out for tender. The detailed survey design would usually be agreed at a later stage, and may contain elements that are conditional on the outcome of the initial stages of the work. Once funding is secure and the scope of work agreed, it is common to consider both the remote sensing and ground-truthing in more detail to ensure the actual survey design is optimal in relation to the objectives of the study.

Basic survey strategy

Remote sensing and ground-truth sampling both provide information pertinent to habitat mapping. As a general approach to mapping, they can be used individually or in combination. MESH recommends they are used in combination, and in a particular order; remote sensing followed by directed ground-truthing. To understand why we recommend this basic survey strategy, and the implications for your mapping programme if you are obliged to take a different approach, we examine the four available options below.

Remote sensing only – gives good spatial coverage allowing the survey area to be segmented into different 'ground types', but further interpretation or ground-truthing is required to identify what each ground type represents. Some remote sensing techniques provide interpretable images in which some ground types can be identified directly from the characteristic 'signature' of the substrate or feature (e.g. sea grass beds in aerial photographs, sand waves in sidescan sonar), but where others may represent a mixture of habitat types as the sensor is incapable of differentiating between different substrates, such as sand and mud. Remotely sensed data generally lacks information about the biological component of habitats so, on its own, will limit the detail you can incorporate into your habitat descriptions and classification. Used alone, remote sensing may provide the lowest-cost option, but this will be at the expense of reduced information content in the mapped outputs.

Ground sampling only – can provide information on both the physical and biological components of the habitats, but maps constructed entirely on the basis of ground sampling techniques are usually incapable of accurately delineating borders between habitats. Sampling design is not informed by prior knowledge of the seabed character (sediment types and bed forms), so must be conducted following a grid-based or depth-stratified design. Sampling scale is usually very small (e.g. 0.1 m^2 grab samples, 200 m long video transects), so sampling intensity needs to remain high in order to ensure that all areas are sampled adequately and evenly. The high cost of such intensive sampling programmes is usually is prohibitive (unless over very small areas).

Remote sensing followed by directed ground-truth sampling is the optimal approach for habitat mapping surveys. The remote sensing allows the survey area to be segmented into ground types, each of which can then be targeted to ensure representative ground-truth sampling. The complete pattern of habitat coverage can then be inferred from the associated data collected by remote sensing and ground-truth sampling, through a process of empirical analysis, direct interpretation or modelling (see *How do I make a map?*). This combination and sequence of sampling proves to be the lowest-cost option for providing maps with both physical and biological habitat information.

Ground truth sampling followed by remote sensing is more effective than relying on either technique in isolation, but the inability to direct ground truth sampling towards known seabed features or different ground types means the potential synergies of using both techniques together can not be fully realised or exploited. Sampling intensity needs to remain high in order to ensure that all areas are sampled evenly. Consequently, using this combination of techniques in this sequence can prove to be the highest-cost option.

RECOMMENDATION

The MESH project strongly encourages you to follow the third of these overall approaches, **'Remote sensing survey followed by directed ground-truth sampling'**, as this has proved to be the most effective and cost-efficient way of producing habitat maps with acceptable levels of confidence and accuracy.

Once you have selected a basic survey strategy, you need to consider the range of sampling tools and techniques that are available and select those that are most appropriate for providing the data and information that the Gap Analysis indicated would need to be collected by new surveys.

Sampling tools and techniques

Surveyors have at their disposal a variety of generic technologies that sample different aspects of the environment. Remote sensing tools include optical, radar, sonar and seismic technologies, which are complemented by direct sampling tools such as grabs and corers and observational techniques like video and photography. Within each generic technology there are a variety of specific tools designed to apply that technology under different conditions or for slightly different purposes (e.g. towed camera sledges, drop-frame cameras and Remote Operated Vehicles with video). In drawing up a survey specification you should have some knowledge of the range of tools available, what data they can provide, and whether or not they are suitable for use in the conditions that might be anticipated during the survey.

Here, we look briefly at a variety of survey tools and technologies, to provide a basic comparison of their capabilities and limitations that will help select a suite of appropriate techniques to list in the survey specification. The three summary sheets used to illustrate this section are available in higher resolution in the resource folder Technique selection v2.ppt A more detailed consideration of each technique is included in the MESH Review of standards and protocols for seabed habitat mapping MESH_Standards_&_Protocols_2nd Edition_26-2-07.pdf.

Remote Sensing Techniques

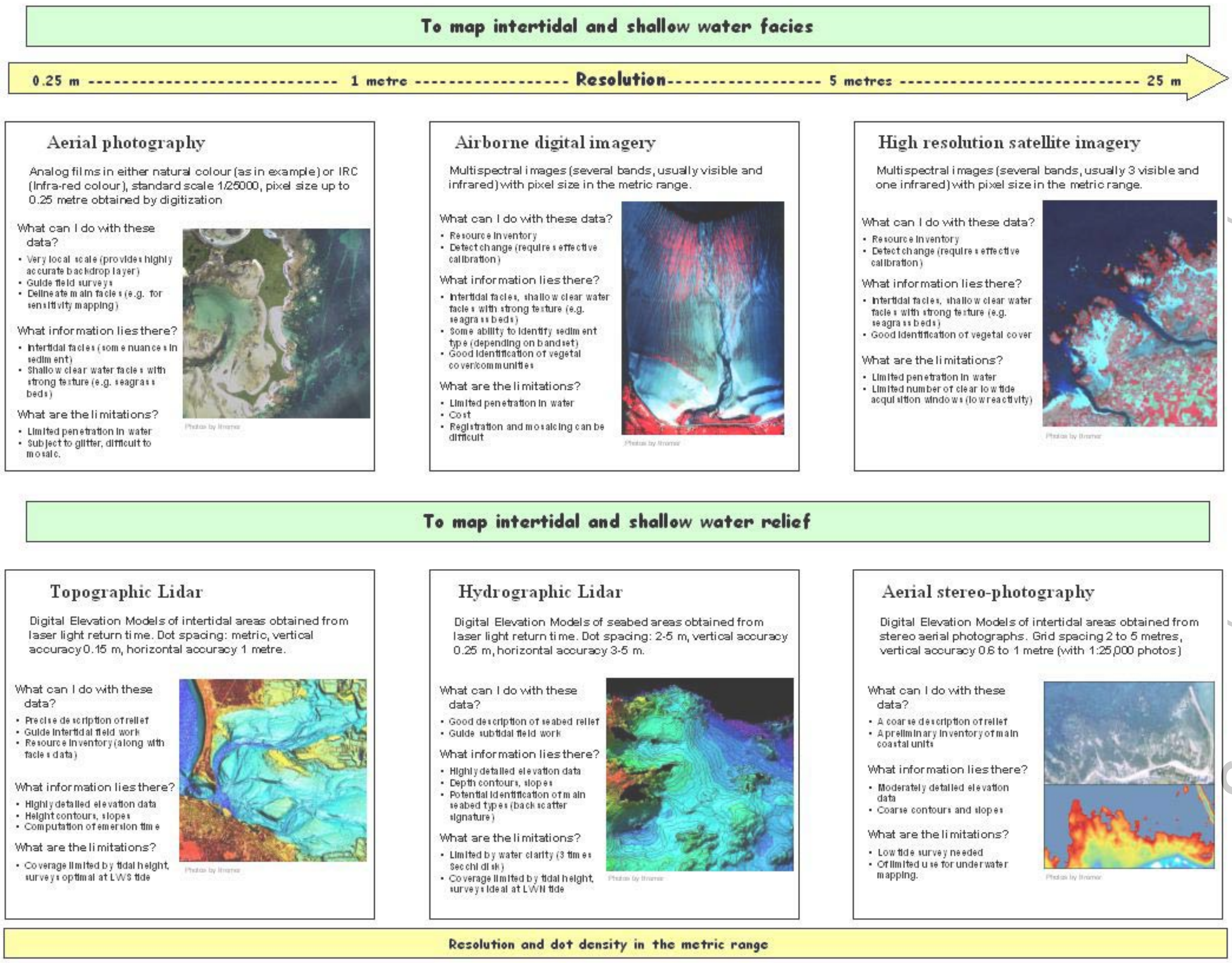
The remote sensing techniques most frequently used in marine habitat mapping fall into two categories:

- Aerial techniques (satellite or airborne) for intertidal and shallow water work (to 20-30 m maximum in clear water)

- Acoustic techniques for shallow and deeper sub-tidal work. They can be used over intertidal areas at high tide but this is unusual as there is greater risk of damage.

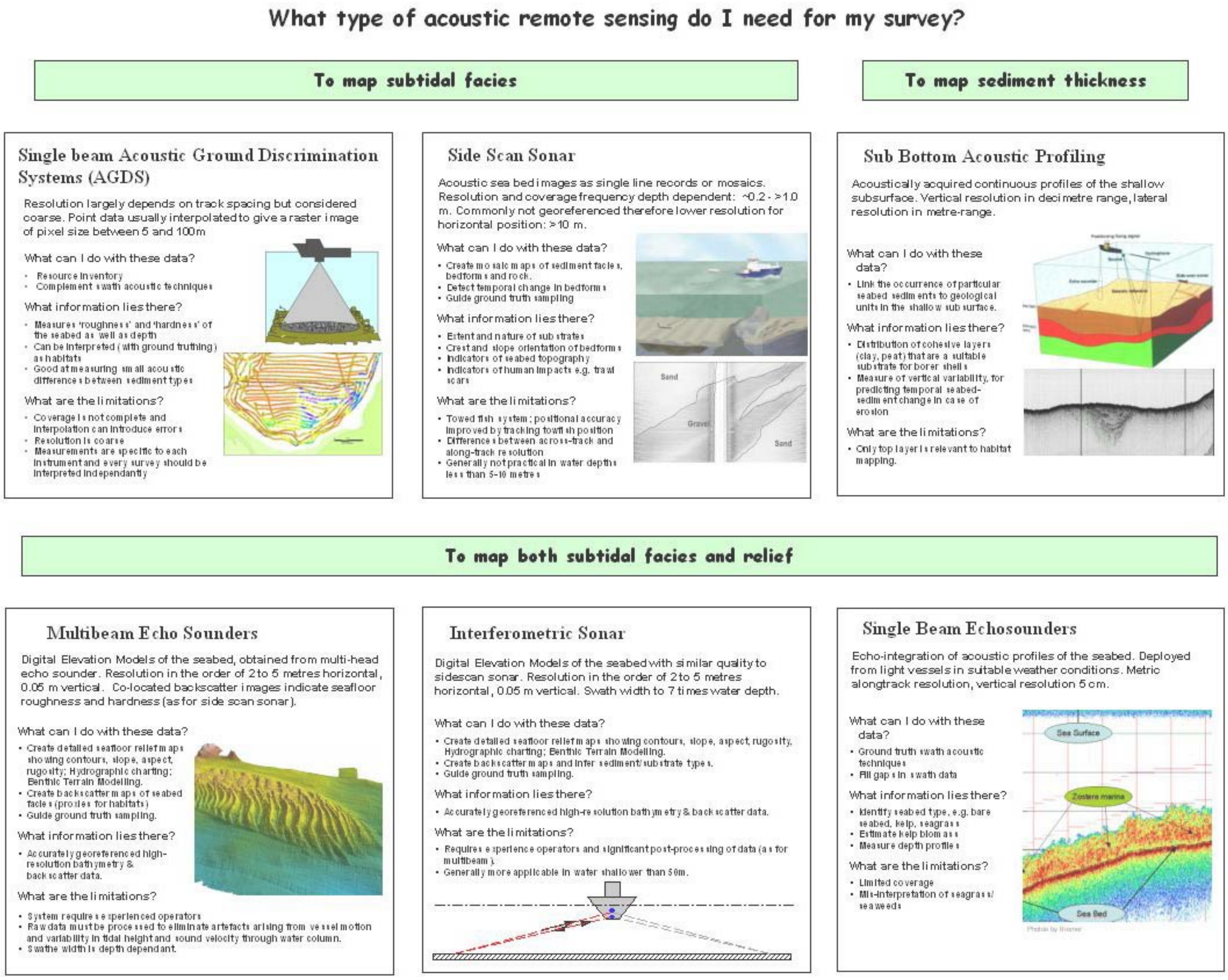
Aerial techniques

For intertidal and shallow water areas, the spatial distribution of seabed facies (i.e. different ground-types) can be mapped using images from satellites and aerial surveys, while topographic relief can be determined using LIDAR (a laser scanning instrument mounted on an aeroplane) or stereo aerial photography. The image below gives more details: click on the image for a larger 'PowerPoint' version.



Acoustic techniques

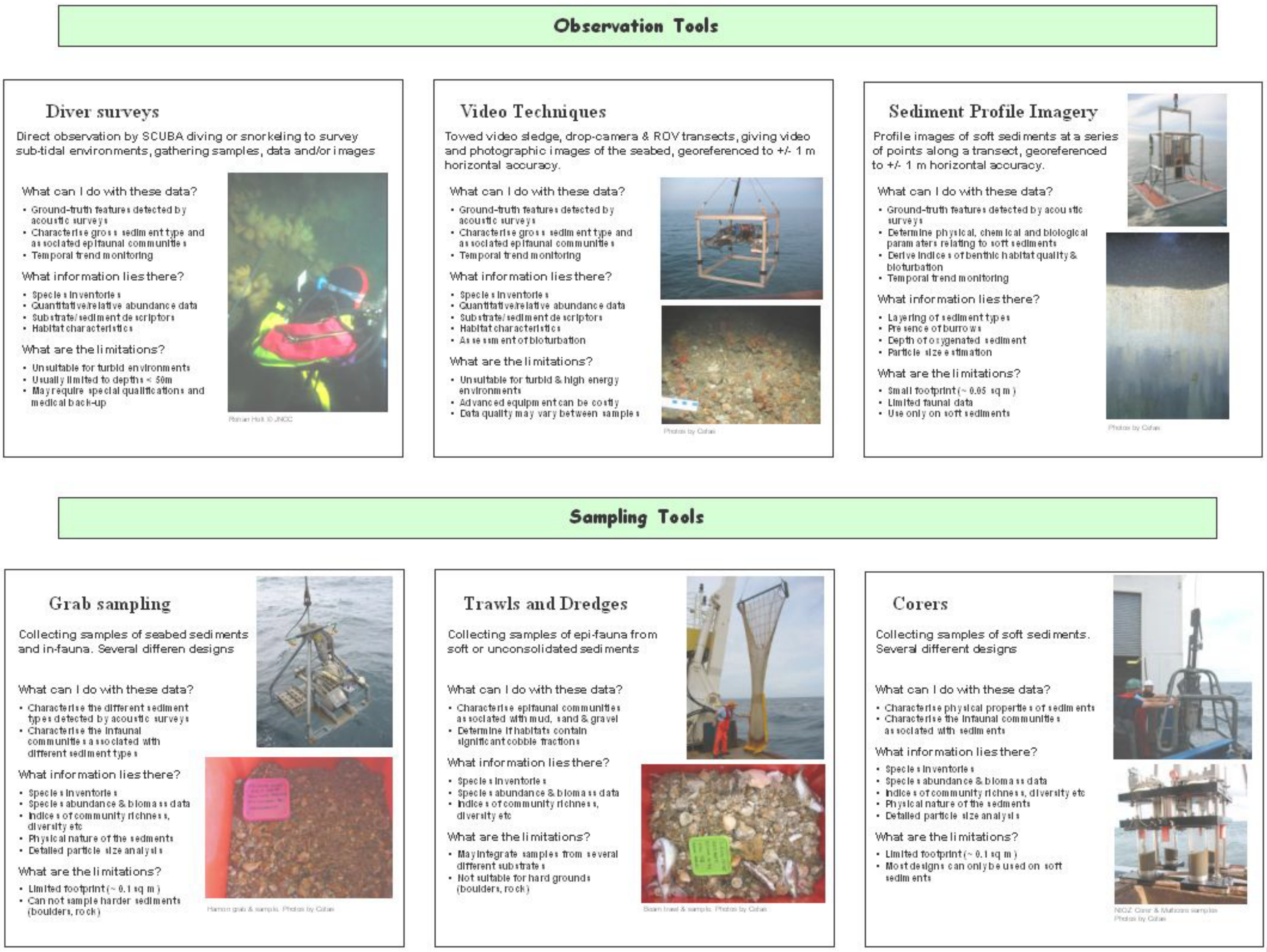
Acoustic techniques can provide information about the surface and sub-surface characteristics of the seabed. For habitat mapping it is usually the seabed surface and the top half metre of the seabed that are of greatest interest as this is where the majority of species live. Sidescan, multibeam and interferometric sonars sense swathes along the seabed that can be mosiaced to building up high-resolution images in which some sediments and bedforms can be recognised and directly mapped. Single beam echo sounders sense a series of points along the seabed and, through an Acoustic Ground Discrimination Systems (AGDS), can build coarse resolution raster images that segment the survey area into different ground types. Some techniques are better for mapping the spatial distribution of seabed facies, while others are better for mapping relief. Some can do both. Lower frequencies are used in sub-bottom profilers to penetrate the seabed to show the thickness of various sediment layers.



Seismic remote sensing techniques are considered a special case in marine habitat mapping. They are frequently used in geological surveys to show profiles through the earths crust and can be of interest in habitat mapping when they record features at or near the seabed surface. The resolution is much lower than in acoustic surveys but the information can provide supporting evidence for interpreting the nature of the seabed, particularly over large spatial areas or in deeper waters off the continental shelf where acoustic techniques may be of limited use. Further information is provided in the section on 3-D seismic imagery.

Ground-truthing Techniques

Ground-truthing techniques generally fall into two categories, observational and sampling techniques. Surveys of the shore and shallow waters tend to rely heavily on human observation, though sampling is necessary to provide quantitative data. In deeper waters, cameras can be deployed on a number of different platforms to observe the seabed but much of the ground truthing relies on the use of sampling devices to collecting samples of the sediment and the benthic infauna and epifauna that are then processed and analysed to provide much of the physical and biological data needed to classify the habitats. Such sampling devices are normally only effective on unconsolidated sediments, so in rocky areas there is a greater reliance on video and photographic techniques.



Varieties of tools and techniques

Many of the different remote sensing, observational and sampling technologies can be further split into a variety of tools that have been designed and developed for specific applications or to perform optimally under specific conditions. Some of the more common ones used in marine habitat mapping are listed in the table and examined in some detail in the MESH Review of standards and protocols for seabed habitat mapping MESH_Standards_&_Protocols_2nd Edition_26-2-07.pdf. For each technique there are sections describing the general principles of operation, the varieties of systems available and their different applications. When drawing up a survey specification or when planning a survey you should be aware that such varieties exist and consult a specialist who can advise you on the tools best suited to your needs.

Varieties of tools within different techniques	
Technique	**Variations**
Aerial remote sensing	
Aerial photography	Oblique or ortho-rectified photographs
Airborne digital imagery	single-, multiple- or hyper- spectral
Satellite imagery	single-, multiple- or hyper- spectral
LiDAR	topographic, hydrographic
Acoustic techniques	
Multibeam echo sounder	range of frequencies, different models optimised for different depth ranges
Single beam echo sounder	range of frequencies, single/dual frequency
Side scan sonar	analogue/digital, range of frequencies, single/dual frequency, modulated frequency (Chirp)
Interferometric sonar	range of frequencies, single/dual frequency
Acoustic Ground Discriminating Systems	some methods analyse signal strength, others analyse waveform
Sub bottom profiling	single frequency or modulated (Chirp), 'sparker'/'boomer'
Benthic sampling techniques	
Grab designs	Hamon, Day, Smith-McIntyre, Van Veen, Shipek,
Core designs	Box, Nioz, Vibrocore, Mutli-corer
Trawls	Agassiz, Beam, Otter
Dredges	Oyster, Scallop, Naturalist, Rallier du Batty, Rock, Anchor
Video/photo	Towed or drop-frame cameras, ROV's

Suitability of the techniques

The process of selecting techniques to be used in the survey must consider not only their sensing or sampling capabilities, but also whether or not they will be suitable for use under the conditions that are expected to be met during the surveys. Even the most robust sampling techniques have their technical and logistic limitations. Grab samplers are ineffective on rock substrates, optical techniques are affected by turbidity, SCUBA divers would not normally work at depth >30 metres. Consequently, different combinations of sensing and sampling tools can be appropriate for different sets of circumstances. The interactive Scoping Tool met in Scope the mapping programme contains a section that allows you to check how the suitability of various sampling techniques changes under different sets of environmental conditions. The use of this part of the Scoping Tool is explained in detail in the section Suitability of survey tools.

3-D seismic imagery

All seismic surveys are designed to image specific target depths. The parameters chosen to achieve the survey objectives may or may not be suitable for imaging the seabed and near seabed events. It is important to properly understand the vertical & horizontal resolution of the 3D seismic as this will impact on the interpretation of the resulting seabed image. Most oil exploration 3D seismic use seismic sources with peak frequencies of approximately 30Hz, giving a vertical resolution of 12.5m. In these circumstances beds thinner than this thickness will not be resolvable. Bulat (2005) gives an example of the impact this has by comparing a TOBI (Towed Ocean Bottom Instrument deep-towed sidescan sonar) image (high-frequency source) of steep-sided downslope channels in the Faroe-Shetland Channel, which are partially infilled with contourite sands (sand accumulations deposited by contour following currents), and the seabed image generated from 3D seismic over the same area. The contourite sands are not imaged on the 3D seismic; instead the steep-sided channels can be followed further up-slope, i.e. the thin sands are effectively invisible to the 3D seismic derived image. In deep-water areas many operators now design their 3D seismic surveys to image the seabed and near seabed as well as the deeper exploration target to remove the requirement for additional geohazard surveys (Bulat and Long 2006). These surveys achieve greater vertical resolutions of 6.25m. The horizontal resolution of 3D seismic is defined by the original 'bin' size of the survey; typically 12.5m but older data is often 25m. Thus features less than this size will not be well imaged.

Suitability of survey tools

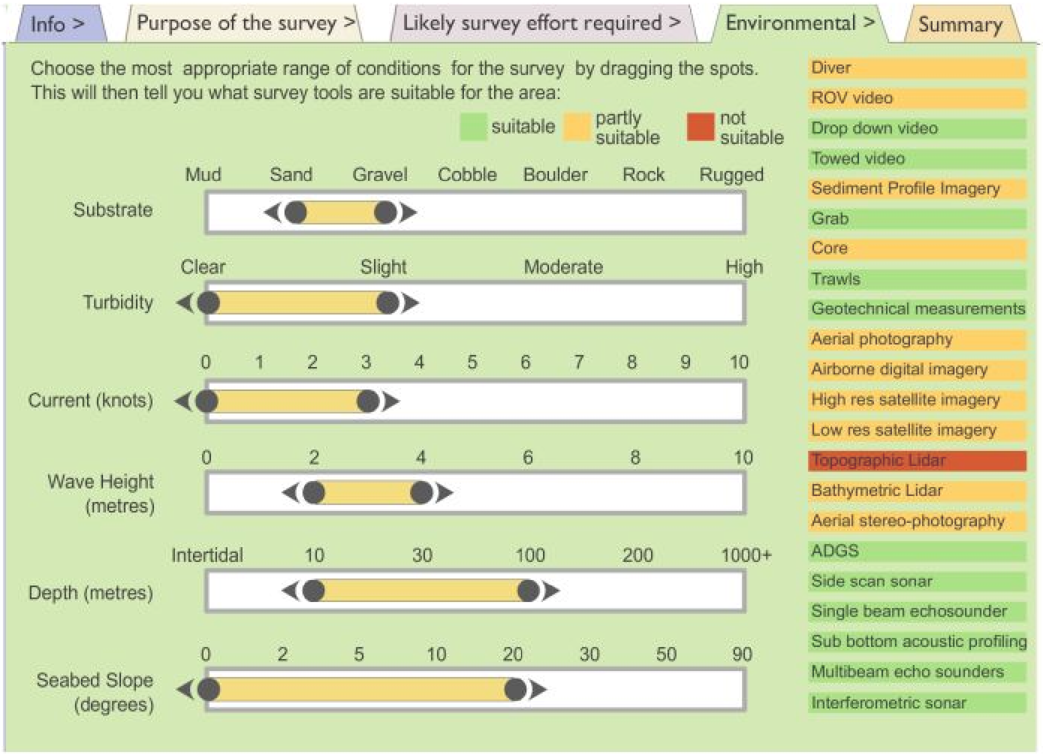
When considering the final selection of a suite of remote sensing and ground-truthing tools to undertake a habitat mapping survey, the following points should be considered.

- The capabilities and limitations of the various tools & techniques
- The optimum combination of tools needed to supply the required information
- The suitability of the tools for the anticipated survey conditions.

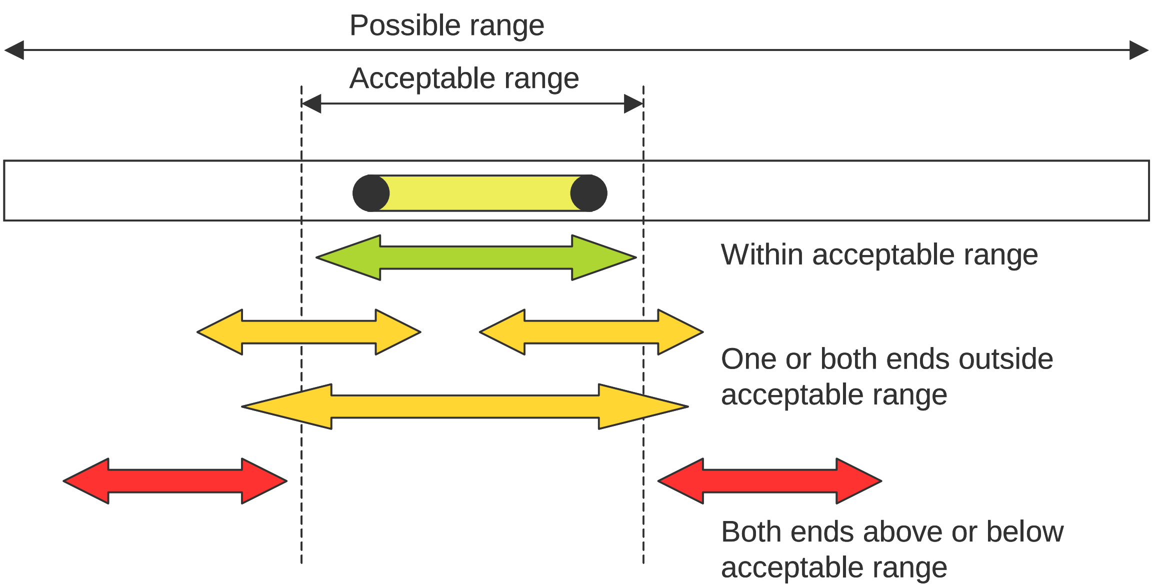
The first two points have already been considered in some detail, so here we will focus on the last. The 'conditions' of the survey cover both the nature of the survey area and the environmental conditions at the survey site(s). Every tool has a range of conditions under which it can operate and for some tools this will be more critical than others.

Taking the example of underwater video techniques, each has a limitation that is critical in deciding which tool to use. ROVs have a limited capacity to make-way against even moderate currents, so towed or drop-frame cameras may be preferred to allow a greater 'operational window' in tidal waters. Cameras towed on sledges are not suitable for rough or rocky grounds, so ROVs or drop cameras would be preferred. Of all the techniques, drop-frame cameras are hardest to operate in a moderate sea-swell as the motion of the ship causes them to rise and fall relative to the seabed making it difficult to maintain an optimum altitude. Water clarity affects all the video techniques, so periods of raised turbidity should be avoided, such as the annual phytoplankton blooms or the daily peaks in tidal flow.

The comments above illustrate the point that there are many factors to consider when selecting the survey tools. If you return to the interactive Scoping Tool Scoping Tool.swf. in the Resources section, you will see that survey conditions are considered under the 'Environmental' tab, as illustrated below.



On the right is a list of survey techniques and in the centre a range of variable survey conditions that may be encountered. The suitability of each technique has been scored against the various survey conditions, and moving the slide bars will change the colour coding in the list of techniques to indicate whether or not they are suitable for the expected survey conditions. If a technique is shown to be 'partly suitable', it means that the upper and/or lower scores for one of the conditions is outside the acceptable range. If a technique is shown to be 'not suitable', it means that the upper and lower scores lie entirely to the left or right of the acceptable range (see below).

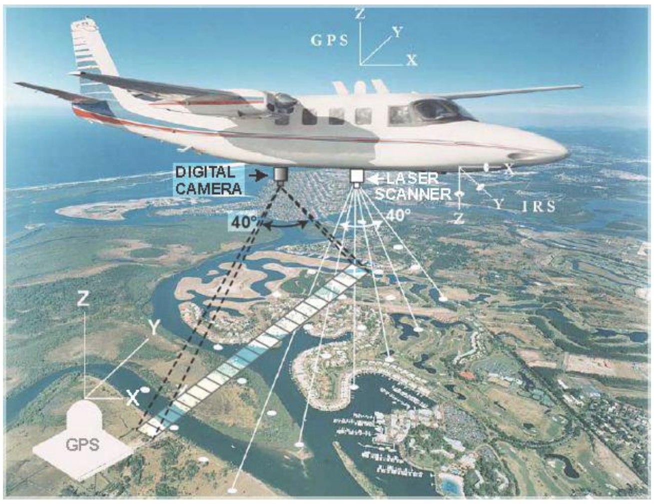


The main thing to look for when using this part of the flash application is when conditions cause a technique to be flagged as 'not suitable' (red). It is normal for techniques to be scored as 'suitable' (green) or 'partly suitable' (amber). Of course, some factors will have no effect on some techniques (for instance 'turbidity' has no influence over the suitability of grab techniques).

Remote Sensing survey strategy

The main strategic issues to consider for the remote sensing (RS) survey are the tools to be used and whether the survey requires full or partial coverage.

As indicated in the section Sampling tools and techniques different remote sensing instruments provide different types of data or information, so these must be matched with the information needs identified by the gap analysis. It will be usual to specify which remote sensing technique (or combination of techniques) are to be used in the survey as this can have a major bearing on the RS survey strategy.

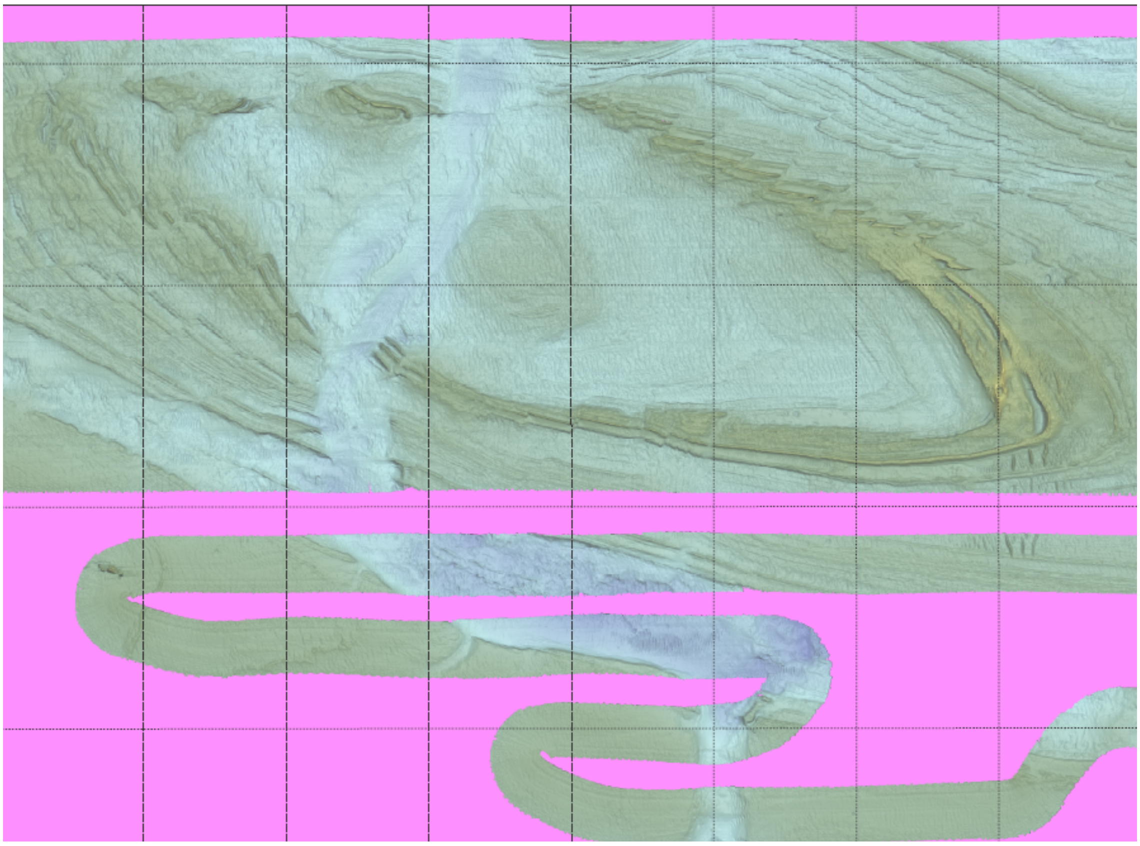


Combined LiDAR and aerial photographic survey. ©Terra Imaging

For aerial and satellite photographic surveys, the default strategy is to achieve full coverage as the swathe width of aerial photography and digital imagery is usually greater than the width of the exposed shore. In topographic and hydrographic LiDAR the default is also for full coverage as the aim is to build a digital terrain model (DTM) showing the topography of the survey area. The survey is conducted in a series of parallel survey lines and any missing lines would leave gaps in the model. The swathe width of the LiDAR instrument can be adjusted to some degree, a wider swath covering more ground at a lower resolution. Hence, if the cost of the survey becomes an issue, the strategic decision would focus on resolution rather than full or partial coverage.

Shallow water surveys use a combination of aerial and acoustic remote sensing techniques, and the strategic issues relate to the diminishing efficacy of the aerial techniques as the depth and/or turbidity of the water increases. Acoustic techniques are not compromised by the turbidity of water, so they can be used to complete the survey, if the water depth is sufficient to make their operation logistically feasible. These issues are discussed further in the section Remote sensing in shallow water where two case studies are presented. To complete a DTM, you will need to select aerial and acoustic techniques that supply positional data in three dimensions (X, Y, Z) and ensure they use the same geodetic system (e.g. Latitude, Longitude, WGS84) and that the two data sets are corrected to a common datum point for zero depth before being merged.

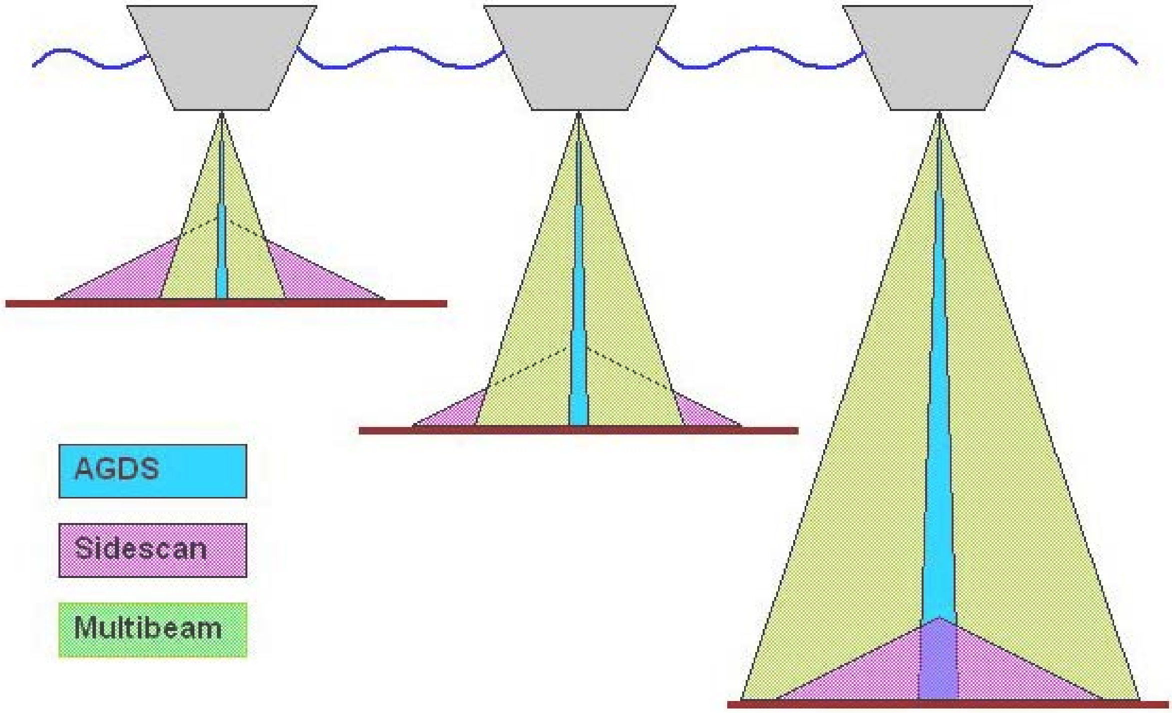
The issue of full or partial coverage has most significance for swathe acoustic surveys, which are also usually run as a series of parallel lines to allow the build up of a full coverage image. The point is illustrated in the multibeam image from an area of the central English Channel. Fine detail can be mapped over the upper area where full coverage has been achieved, but in the lower area of partial coverage only the larger features that span the data gaps can be mapped. The incentive to move from full to partial coverage is one of survey cost and time. Acoustic surveys are approximately 20 times slower than aerial surveys, proceeding at ~ 7 knots compared to flight speeds of ~150 knots.



Multibeam image from central English Channel showing full and partial coverage of an area of faulted rock outcrops bisected by a north-south trending palaeovalley. Grid lines at 30 second intervals (~0.5NM).

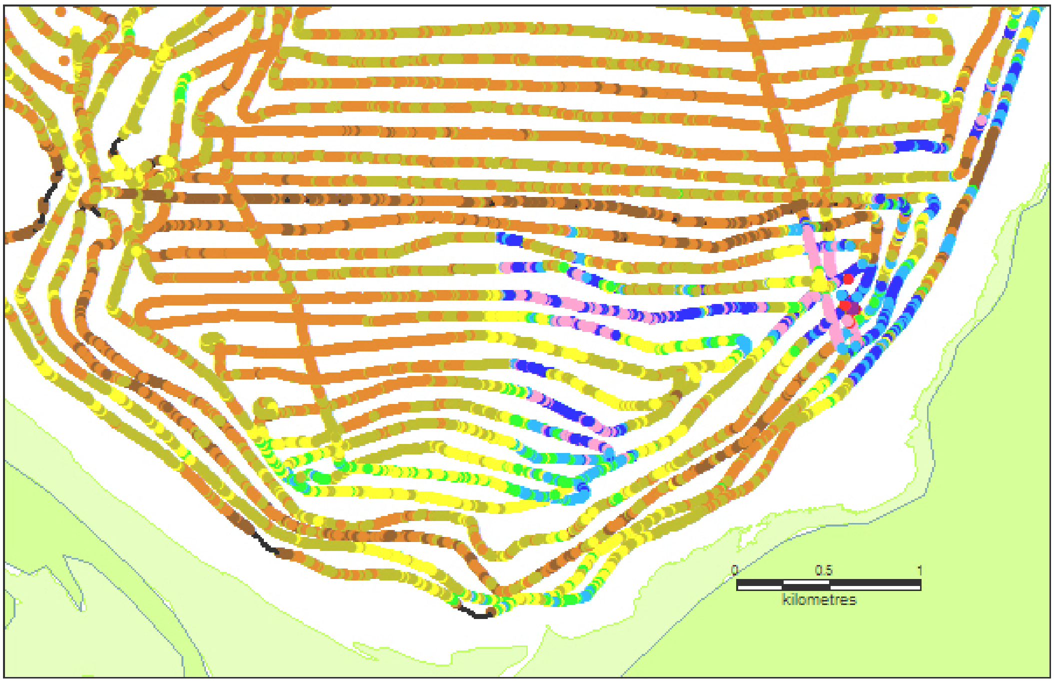
Full coverage is mandatory for finescale mapping and has greatest value in highly heterogeneous areas. It may not be necessary for mapping broader scale features or areas where the substrate is largely homogeneous (e.g. extensive sand plains). Here, quasi 'full coverage' can be achieved from less than 100% coverage by interpolating, by eye, across the gaps between survey lines (as seen in the example of a partial coverage survey in the section *Specify new survey work*). Clearly, this can only be done for features that actually span the gaps, so wider gaps lead to fewer features on the map and more generalised segmentation. It is not usual to interpolate over more than twice the swath width (~33% cover) without supporting inference based on complementary data (usually at a broader spatial scale). Partial surveys over large areas (thousands of square kilometres) may adopt a 'corridor' strategy, building full coverage over 1 km wide corridors spaced 5 to 10 km apart. This is a type of nested survey, allowing fine and intermediate scale detail features to be recognised within the corridor and broad scale features to be mapped over the survey area. For more detailed discussion on this topic refer to the section Partial coverage acoustic surveys.

You should be aware that for hull mounted acoustic sensors, like multibeam and AGDS systems, the swathe width increases with increasing depth of water, while for towed systems that are flown at a constant height above the seabed the swath width is constant (see illustration). Hence, towed systems give greater coverage in shallow water and hull-mounted systems in deeper water. This can influence the choice of acoustic system and the cost effectiveness of the survey. If conditions permit it is recommended to run several acoustic systems simultaneously as they supply complementary data types. It should be left to the survey deign stage to determine the spacing to be used between survey lines, But the survey specification should indicate what type of acoustic sensor should be used and whether the survey requires full or partial coverage.



Effect of increasing water depth on swath width for hull mounted (multibeam & AGDS) and towed (sidescan) acoustic systems

Single beam Acoustic Ground Discrimination Systems (AGDS) can be considered to provide a sequence of point samples along the survey track. In normal operation at moderate depths (less than 30m) a maximum spatial resolution of 25m might be achieved. When several tracks are run over a survey area, a pattern of ground types can be revealed (see illustration). Interpolation techniques are applied to the point data (in computer applications) to provide a pseudo ‘full coverage’ raster image suitable for segmenting the survey area. Track spacing is the main issue to consider in an AGDS survey strategy, as interpolation between tracks become less reliable as the spacing increases. A 50 m spacing is considered a usual minimum and a spacing greater than 500m is not recommended (Foster-Smith, 2007). Nowadays, acoustic surveys tend to favour swath systems due to their greater resolution, but AGDS is commonly used as a secondary system as it can help interpret swathe images.

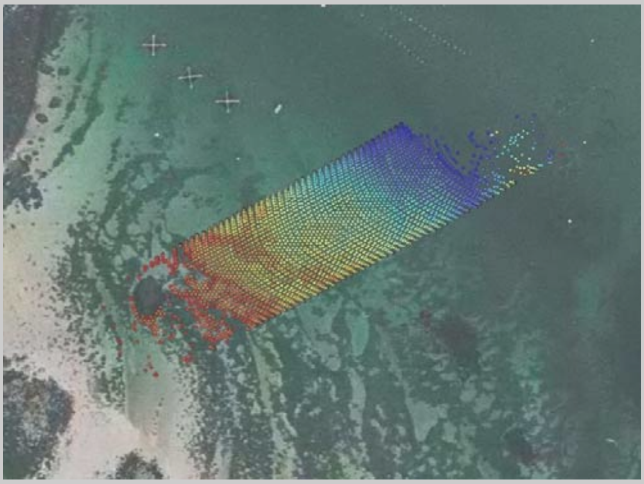


Example of an AGDS survey. Different colours indicate different ground types.

In summary, for the purpose of habitat mapping 'full coverage' surveys are highly desirable as they allow segmentation of the survey area to consider fine intermediate and broadscale features. They are also the most reliable way to approach direct mapping projects. Fine detail can always be generalised to provide broader scale maps over large extents. Partial cover surveys may meet the needs of intermediate and broadscale mapping studies and present significant cost saving opportunities.

Remote sensing in shallow water

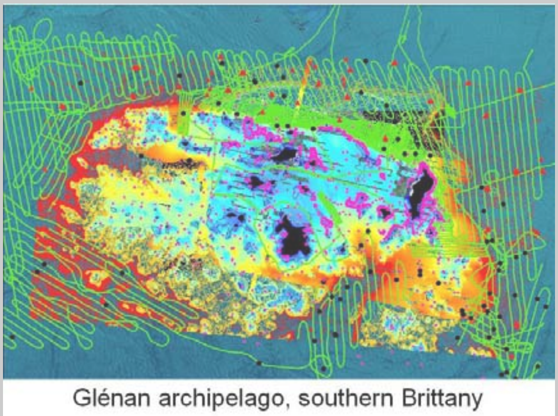
As one travels from the coastline seawards through the waterline the efficiency of visible remote sensing will decrease abruptly until becoming totally 'blind' in the 10-20 metres depth zone (depending on water clarity). So, simply ensuring 100% spatial coverage does not guarantee that you will get data for the whole area; there will be data gaps where the environmental conditions (water depth/turbidity) limit the effectiveness of the remote sensing technique. These data gaps can be filled using shallow water acoustic surveys, although these may be limited in their ability to access complex shallow water rocky coastlines, and the cost per unit area of survey will be high due to the narrow swath width of acoustic systems in shallow water.



Lidar_bathy_Abers_t.jpg

As water depth increases, visible remote sensing becomes less effective. Note the break up of the bathymetric Lidar data (coloured dots) in deeper water.

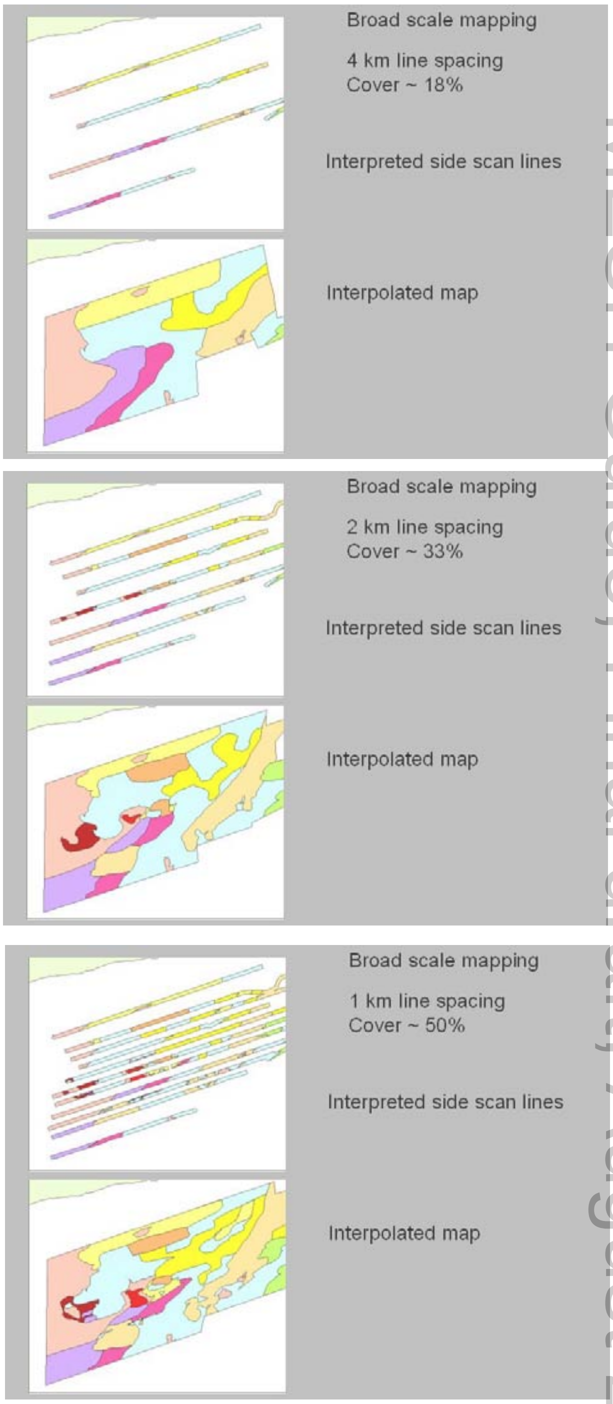
Even 100% coverage of say two techniques in shallow water (e.g. surveys of elevation and ground types) would generally yield a patchwork of sub-areas where both, one or none of the techniques proved effective. The remaining data gaps would have to be filled by interpolation techniques, with possibly a higher ground-truth sampling effort than elsewhere. It is instructive to view the slide show for the Glénan archipelago case study Glenan survey strategy.ppt and consider the patch-work of coverage provided by the variety of remote sensing techniques.



Glenan survey strategy.jpg

A second case study from the French 'Rebent' programme is presented in the document Mapping shallow coastal habitats.pdf and demonstrates the application and utility of acoustic techniques in mapping shallow coastal benthic habitats.

Partial coverage acoustic surveys



The sequence here illustrates how the detail in the mapped output increases with progressively greater density of cover. The study relates to a broadscale area surveyed by sidescan sonar at progressively closer line spacing (Coggan, 2006). Each side scan line was interpreted separately, and coloured to differentiate distinct classes of sediment and bedform (e.g. sand waves, gravel ribbons etc). A quasi-full coverage map was then produced by interpolating (by eye) between the interpreted lines.

As coverage increased, the interpolation was guided more by information content that 'guess-work', so reducing the uncertainty associated with the final map. The map produced from 4 km line spacing (equivalent to ~18% cover) missed some significant bedforms that appeared in the maps from 2 km and 1 km line spacing (~33% and 50% cover respectively).

There appeared to be less difference between the interpolated maps derived from 2 and 1 km line spacing than there was between those derived from 4 and 2 km line spacing. The '1 km' map had more intricate detail than the '2 km' map but they were generally very similar. This indicated that most of the broad scale variability in this study area was being captured at a coverage of between 30 and 50%. Note that this level of accuracy might require a different coverage in other study areas.

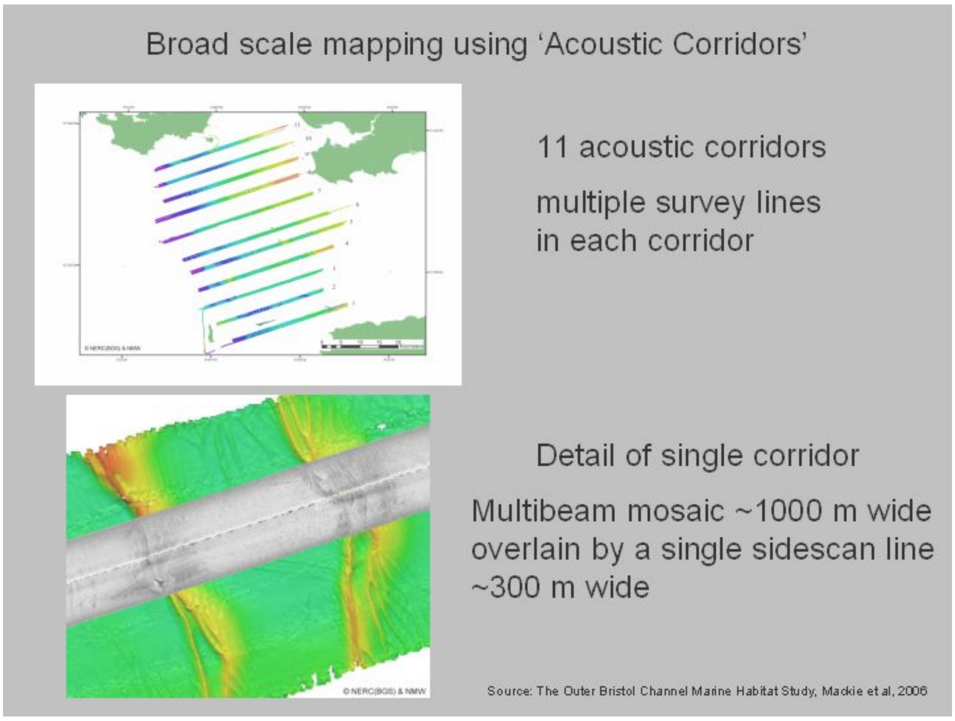
Full survey coverage (100%) was achieved over a central band of the study, but provided only marginal improvement to that section of the map as the interpolation was now very accurate. As full coverage would cost twice as much as 50% coverage, the marginal benefit would not appear to justify the additional cost for such broadscale surveys. The PowerPoint slide show Remote sensing coverage.pps helps visualise the differences between the maps.

When surveying smaller areas, there is not usually such a financial barrier to obtaining full coverage acoustic surveys, as the absolute costs involved are far lower (more affordable) than for large area surveys (several thousand Euro as opposed to hundreds of thousands or millions). The requirement for greater detail, confidence and accuracy is also usually higher for finescale site-specific surveys and full coverage is therefore recommended.

There is inevitably a trade-off between reduced coverage and reduced confidence in the mapped output, and a need to balance the deployment of resources (money, time, personnel) with the required quality of the survey and resulting map. There is no empirical answer to the question ‘How much coverage is required to provide a map with the desired level of confidence?’ as this depends largely on how that coverage is achieved and the heterogeneity that is found in the survey area. Clearly, confidence will be higher for a 30% coverage survey of a homogeneous area of fine sand than for the equivalent coverage of a highly heterogeneous area of mixed substrata and rock outcrops.

The critical point to recognise is when your confidence in the outputs of the survey drops below what was deemed acceptable in the scoping report. There will inevitably be pressure from or on funding bodies to reduce costs by reducing coverage, or to appear to maximise cost-efficiency by spreading a fixed resource over a larger area, so it is important to recognise the value of this feedback loop in highlighting false economies and under funding.

Where broadscale mapping is concerned (large areas with low resolution and accuracy), coverage is likely to be limited (by cost) to less than 50%, so the acoustic survey should aim to detect broadscale changes in seabed character (sediment type and bedform) as this type of information is relevant to the scale of the survey. Bedforms exist at spatial scales larger than the swathe of sidescan or multibeam sonar, so single survey lines are rarely effective in identifying and mapping such features. Two recent studies (Mackie et al. 2006 and James et al., 2007) have demonstrated that a ‘corridor’ approach can be an effective strategy for acoustic surveys, running several adjacent lines to build up full coverage of a 1 km wide corridor of the seabed, allowing a far greater appreciation of the nature of the bedforms. Several corridors are surveyed to build an interpretation of the large area.



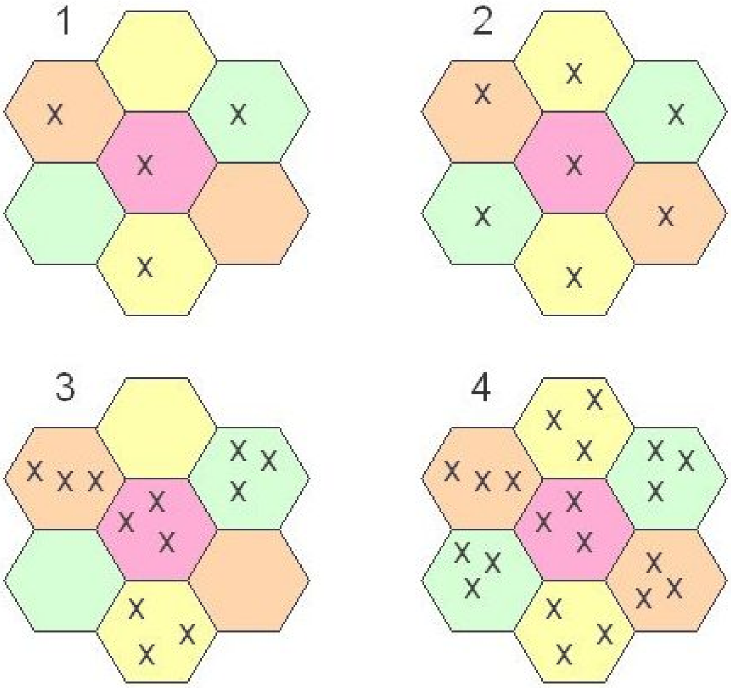
The example illustrated here is from the Outer Bristol Channel (Mackie et al. 2006), where each corridor was surveyed using a suite of three geophysical systems, multibeam echo sounder, sidescan sonar and sub-bottom seismic reflection profiling (surface tow boomer). The 1000 m wide multibeam mosaics allowed confident identification of major and minor bedforms, with the sidescan sonar and seismic profiling providing further information on the nature of the substrates.

In all cases where no previous acoustic data exists, a brief 'pilot' survey of the area is highly recommended. A rudimentary grid of survey lines can provide valuable information on seabed heterogeneity that will inform your decision about the coverage required by the remote sensing survey proper.

Ground Truth Survey Strategy

At this stage in the planning process, the main issue to consider for the ground-truth survey is the overall sampling strategy, which has to strike a balance between cost and effectiveness. Too few samples will severely limit the power of any data analysis and the ability to classify habitats, too many will result in being overwhelmed with samples that are costly and time consuming to process. The choice of the sampling strategy will influence confidence in the final mapped output, so the aim should be to provide representative sampling that fits the purpose of the particular mapping project.

The point is illustrated in the schematic diagram, showing four theoretical sampling strategies. The coloured polygons represent the segmentation of the survey area into different ground types following a remote sensing survey. The first strategy samples each ground type just once, allowing some comparison between ground types but forcing the assumption that every ground type is homogeneous. The second strategy samples a single station in every segmented area, allowing a rudimentary test of similarity within and between different ground types. The third strategy samples a number of stations within one occurrence of each ground type, testing the homogeneity of that segment, but forcing the assumption that the selected segment is representative of all other occurrences of that ground type. The fourth strategy samples multiple stations in every segment of every ground type. This allows full analysis of variation within and between ground types.



Schematic diagram showing four sampling strategies.

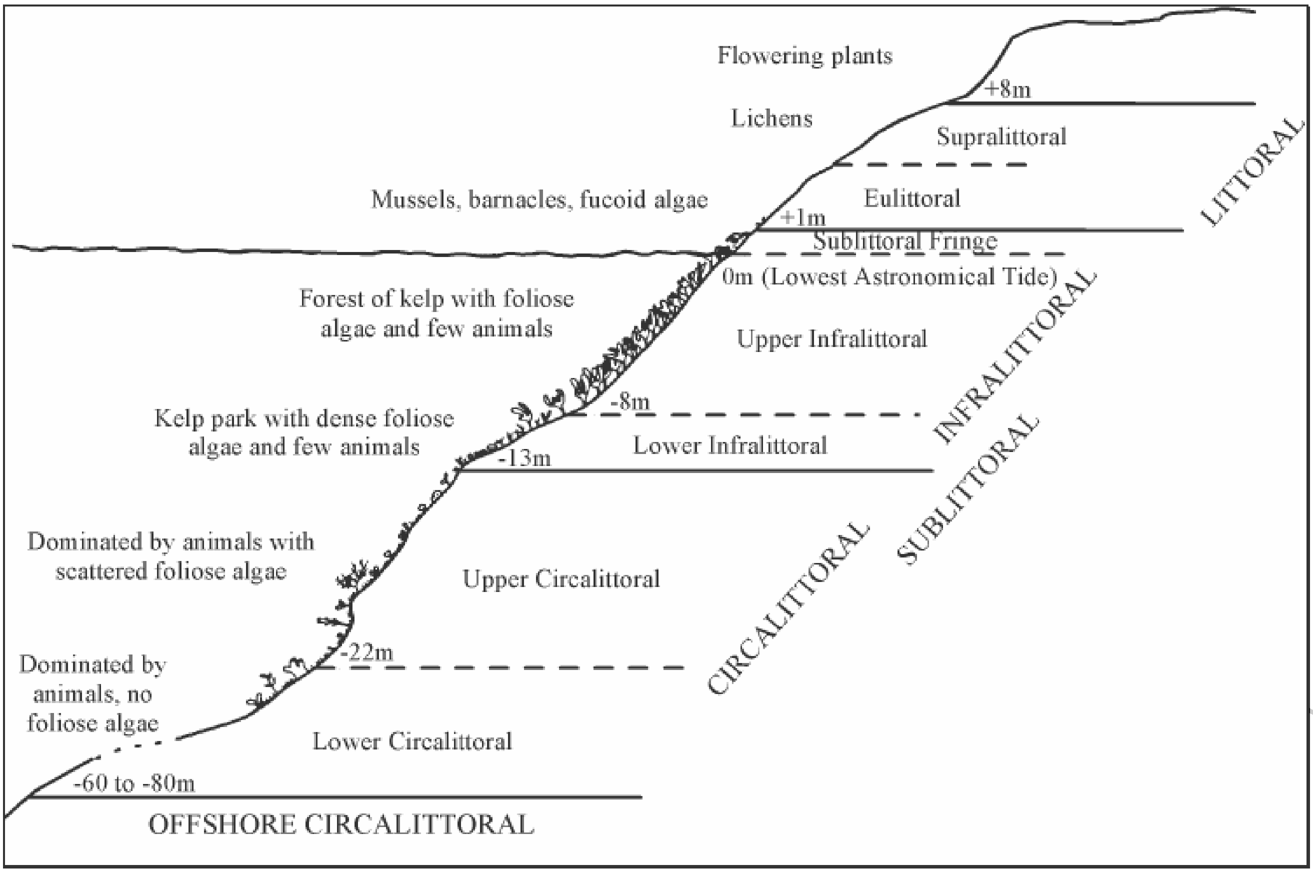
The first strategy is the minimum requirement for ground truthing; if a ground type is not sampled, it cannot be assigned a habitat class. The fourth strategy may be highly desirable but in most cases would be impractical due to the large number of segmented areas that need to be sampled and the large number of ground types. It may have application in site-specific monitoring studies where this level of detail is needed or areas where there are very few ground types, so generating a manageable number of samples. Practical sampling strategies do not frequently conform to the theoretical models presented here, and in many cases the pragmatic solution will be somewhere between strategy 2 and 3, sampling all the ground types but taking replicate samples from a representative selection of each.

A further consideration is the requirement for validation samples. These are samples collected during the normal course of the ground-truth survey, but they are not used in making the map. Instead, they are set aside and used to test the classification and spatial accuracy of the map once it has been produced. They should be an integral part of studies that rely heavily on modelling, as such formal accuracy tests are important in judging the level of confidence that can be placed in the mapped output. Validation samples are rarely used in direct mapping studies where ground types are assigned a habitat class on the basis of observation rather than empirical analysis or modelling.

The ground-truth strategy must also consider the need to stratify sampling to account for gradients in environmental variables that are known to influence habitat characteristics. Four such variables are shown in the table, with suggested stratifications. Usually, a single variable will be the main influence, such as salinity in an estuarine study, exposure on a shore study or depth in a sub-tidal study. In some cases a secondary variable may become influential in certain parts of the survey area, such as the increased tidal stream within narrow channels. Stratifying multiple variables can lead to a bewildering matrix of strata that are impractical to sample, so the guidance offered is to focus on those variables whose range over the survey area has most influence on habitat type.

Stratification of environmental variables			
Depth below 'Low Water' (metres)	**Wave Exposure (categorical)**	**Salinity (parts / 1000)**	**Maximum tidal stream (knots) (ms^{-1})**
0-10	Extremely sheltered	Low (<18)	Very weak ((negligible))
10-30	Very sheltered	Reduced (18-30)	Weak (< 1) (<0.5)
30-50	Sheltered	Full (30–35)	Moderate (1-3) (0.5 – 1.5)
50-100	Moderately sheltered	Variable (18↔35)	Strong (3-6) (1.5 – 3)
100-200	Exposed		Very strong (>6) (>3)
200–500	Very exposed		
500-1000	Extremely exposed		
>1000			

Where the survey area includes a number of recognised biological zones (littoral, infralittoral, circalittoral, as illustrated in the diagram from Connor et al. 2004), priority should be given to sampling each of these zones, before considering any further stratification according to environmental variables. These biological zones reflect a vertical stratification of environmental conditions in the marine environment and the fundamental influence this has had in determining the nature of the habitats.



Biological zonation of marine habitats from 'The Marine Habitat Classification for Britain and Ireland' Version 04.05 (Connor et al. 2004)

Finally, it is not usually appropriate to specify which ground sampling tools or techniques should be used at this stage in the planning, because that selection should be informed by the outcome of the remote sensing survey. However, depending on the information needs, the survey strategy may specify that sampling would be limited to a particular genre of techniques or should exclude others. For example, if the purpose of the survey is to map a particularly rare or fragile habitat, it would be important to stipulate in the ground-truth survey strategy that no destructive sampling techniques are to be employed and that all information must be collected through by observation only.

Survey specification

Survey spec to include:

- The types of data and metadata required
- The data quality standards
- Spatial coverage and data density
- Proportion of remote sensing : ground-truth sampling
- The quantity of data required ('reserve' for testing).
- Options for the survey strategy (e.g. full, nested)

Habitat surveys can be very demanding on resources (time, money, equipment & personnel), so it is important to optimise the survey strategy and survey design to make the most efficient use of the available resources. The survey programme will have identified a number of different types of data that need to be collected and these will require a variety of survey techniques and sampling technologies. There is often a logical sequence in which the work should be carried out. It is usual to conduct the remote sensing survey first in order to draw up a draft physical map, which will then inform the selection of sites to be sampled on a ground-truthing survey (Figure CH2F3).

The survey **strategy** will address factors such as:

- Which sampling techniques will be used (remote and direct sampling)
- The logical sequence of work (remote sensing followed by ground-truth sampling)
- The survey design (grid-based, stratified, random stratified, nested)
- Coverage required from remote sensing.
- The strategy for ground truthing, including the combination of techniques to be used and the degree of replicate sampling.

Having identified the data gaps, a specification for the survey programme can be drawn up (Table Ch2T4 & 5). It is likely that the new surveys will divide naturally into two phases, the first focusing on remote-sensing techniques and the second on the ground-truth survey. The requirements for the ground-truth survey will often be conditional on the outcome of the remote sensing survey. The survey programme should identify relevant standards and protocols to be used during data collection and processing.

Survey programme: Area X, English Channel	
Phase 1. Remote sensing	Undertake new acoustic surveys of Area X comprising: Full multibeam bathymetry coverage to IHO Order 1 standard. Simultaneous collection of multibeam backscatter and sidescan sonar (possibly combined with seismic profiling). Interpret sonar data to delineate and characterise acoustically-distinct areas into facies and bedforms.
Phase 2. Ground truthing	Conduct a separate directed ground-truth survey targeting acoustically distinct areas identified in Phase 1. Follow standards and protocols given in MESH 'Recommended Operational Guidelines' Use a 2-way stratified sampling design. 1) two depth strata; 10-20 m depth and >20 m depth 2) acoustically distinct areas

	For each depth zone sample representative substrates to determine ➢ the physical nature of the sediment (lithology, granulometry – Folk classification) ➢ the distinctness of boundaries between acoustically distinct areas ➢ variability of substrates within acoustically distinct areas ➢ the species composition of the infaunal communities in unconsolidated sediments (quantitative, abundance & biomass) ➢ the species composition of the epifaunal communities on unconsolidated sediments (semi-quantitative; for errant forms - abundance & biomass, for attached forms, relative abundance and biomass) ➢ the species composition of the attached fauna on consolidated sediments (semi-quantitative; relative abundance) ➢ the association between attached fauna and substrate type (video observation) ➢ the nature of organisms that provide structure to the habitat (e.g. biogenic reefs)

Hypothetical example of a survey programme for offshore survey in the English Channel.

Survey programme: Area Y, Coast of Brittany	
Phase 1. Remote sensing	a) Undertake a full coverage dual Lidar survey of shallow water and intertidal parts of the site, within the 15-20 metres depth line. Undertake a full coverage of the same area with either aerial photography or digital imagery (use satellite imagery if resolution/timeliness adapted) b) Run preliminary interpretation of photography/imagery (either manually or with unsupervised classifications) with the help of Lidar isocontours to build ground truth strategy
Phase 2. Ground truthing	Conduct ground-truth survey (ground + diver + light vessel with grab and single beam echo sounder) with two targets a) run transects to check dubious transitions, b) sample a number of individual locations in a stratified way. Follow standards and protocols given in MESH 'Recommended Operational Guidelines'. Part of the data will be used to interpret, another part to quality check. At each location sample representative substrates to determine : ➢ the physical nature of the sediment (granulometry – Folk classification by hand or light grab if feasible)

	➢ the distinctness of boundaries between distinct areas on imagery (visual observations) ➢ the species composition of the infaunal communities in unconsolidated sediments (semi-quantitative) ➢ the species composition of the attached fauna/flora on consolidated sediments (semi-quantitative)

Hypothetical example of a survey programme for an intertidal and nearshore survey off the coast of Brittany.

Links to other topics in the current section:

Sampling tools and techniques

3-D seismic imagery

Scope the mapping programme

Suitability of survey tools

Sampling tools and techniques

Remote sensing in shallow water

Example of a partial coverage

Partial coverage acoustic surveys

Links to resources:

Technique selection v2.ppt

MESH_Standards_&_Protocols_2nd Edition_26-2-07.pdf

Suitability of survey tools

Mapping shallow coastal habitats.pdf

Remote sensing coverage.pps

Optimise the Remote Sensing

Several tentative survey designs may have been considered when developing the survey specification, but optimising the survey design can only begin in earnest when the survey objectives and strategy have been agreed. The aim is to make best use of the resources available to maximise the overall effectiveness and cost-efficiency of the survey. There is clearly a need to be aware of the previous stages in the planning of the programme, including the Scoping Report and Gap Analysis.

In remote sensing (RS) surveys, the simultaneous use of several different instruments makes efficient use of the survey platform (aircraft or ship) by removing the need to repeat the same survey lines for each instrument. However, as not all instruments work optimally under the same conditions (e.g. speed, altitude, depth), careful consideration should be given to the survey design to favour the 'most important' (principal) instrument while still allowing the others to collect data of an acceptable quality. The survey specification will likely determine which is the principal instrument.

Full coverage RS surveys are usually run in a series of parallel lines, building up a mosaic image of the ground or seabed. The separation between survey lines (track spacing) depends on the width of ground covered by the instrument (swath width), which in turn depends on the type of instrument used and its altitude above the ground or seabed. In some instruments the swath can be adjusted, a narrower swath usually giving a higher resolution. Optimal track spacing for full coverage surveys therefore depends on the characteristics of the principal instrument and of the area being surveyed. For hull-mounted instruments, swath width typically increases with depth to seabed, so surveys of shallow waters will need closer track spacing than those in deeper waters. This is not the case for instruments towed (or flown) at a fixed altitude above the seabed. There may also be an optimal orientation for the survey lines, for example running parallel to a major slope to maintain a constant swath width along individual survey lines.

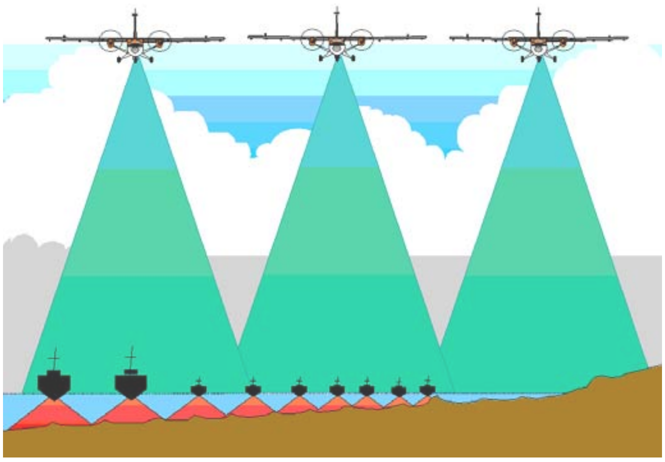


Illustration of track spacing and swath width for airborne LiDAR and shipborne multibeam sonar surveys. Image courtesy of Optech Incorporated.

Surveys of shallow water can use both optical (airborne) and acoustic (ship-borne) techniques and balance coverage between the ability of the optical techniques to penetrate the water and the ability of the vessels to access the shallows. Shallow turbid waters may not be amenable to either technique.

While the survey strategy will have indicated which generic RS techniques should be used, the optimal survey design determines the specific combination of instruments and how they are best deployed. Particular attention should be paid to the methods by which the data will be georeferenced, as this influences the spatial accuracy and precision of the mapped output. Selecting the optimal track spacing for partial cover surveys can be helped by running a few 'pilot' survey lines, usually in a perpendicular or grid pattern, to assess the heterogeneity/homogeneity of the survey area

All remote sensing surveys benefit from some ground sampling to provide reference material that gives meaning to the remotely sensed data. Many remote sensing techniques return streams of data that are, in themselves, meaningless numbers. Ground validation samples allow the range of data values to be segmented to reflect different ground types (supervised classification). If such samples are not available, the data-range may be segmented into artificial blocks, or by seeking 'natural' cluster groups (unsupervised classification). The survey design may consider running instruments over known ground types ('training' or 'calibration' sites) to identify their characteristic 'signatures'. The segmentation of data is important, as it is the basis on which the survey area is divided into different regions that will be targeted for ground-truthing. Where a remote survey technique produces an interpretable 'image' of the shore or seabed (e.g. aerial photography, sidescan sonar) regions may be delineated directly, by eye.

This section of the planning should end with a draft plan of the remote sensing survey that can be handed to those who will conduct the survey to check operational feasibility (considerations of flight paths, shipping lanes, navigation hazards etc).

Suites of remote sensing instruments

It is usually the case that one particular type of remote sensing instrument will provide one particular type of data, so several instruments will be needed to collect the range of data required in the production of habitat map. Two of the most important factors determining the nature of habitats are elevation (height above or depth below sea level) and the nature of the substratum, as these determine the environmental conditions under which any marine organism or community must live. Consequently, instruments that provide information on topography and 'ground type' are heavily favoured in habitat mapping studies over instruments that provide other types of data commonly associated with marine science, such as sea surface temperature, irradiance, chlorophyll-A concentration and current or temperature profiles. This is not to say that other data types are of no use or merit; much depends on the nature of the area that is to be surveyed.

Selecting a suite of remote sensing instruments will therefore usually begin with those that provide the fundamental information, topography and ground type. Studies of intertidal areas commonly use LiDAR to determine topography and photography to discriminate ground types, while sub-tidal studies frequently select a multibeam echo sounder to provide bathymetry and sidescan sonar for ground discrimination. The popularity of these combinations reflects their ability to provide a digital terrain model (DTM; a 3-dimensional representation of the topography of the shore or seabed) segmented into areas representing different ground types. They are, however, not the only combinations able to do this and they are not universally suited for all survey needs.

Selecting two remote sensing systems that provide the same type of information infers some degree of redundancy, which may be seen by some as unnecessary but by others as a valuable insurance against malfunction or error. In some cases, such as satellite and aerial photography, two instruments may be selected that give precisely the same type of output (i.e. a photograph) but the information content remains complementary as each provides a different coverage and resolution and so serves a nested survey strategy.

Where multiple instruments will be selected to run simultaneously on the same platform (aircraft or ship) it is important to check there will be no interference between the RS instruments themselves or between the RS instruments and other devices needed for the safe running of the platform (e.g. radio and navigation systems). Interference can produce unwanted systematic errors and/or unexplained artefacts in the survey data, both of which mask reality and hinder data processing and/or interpretation.

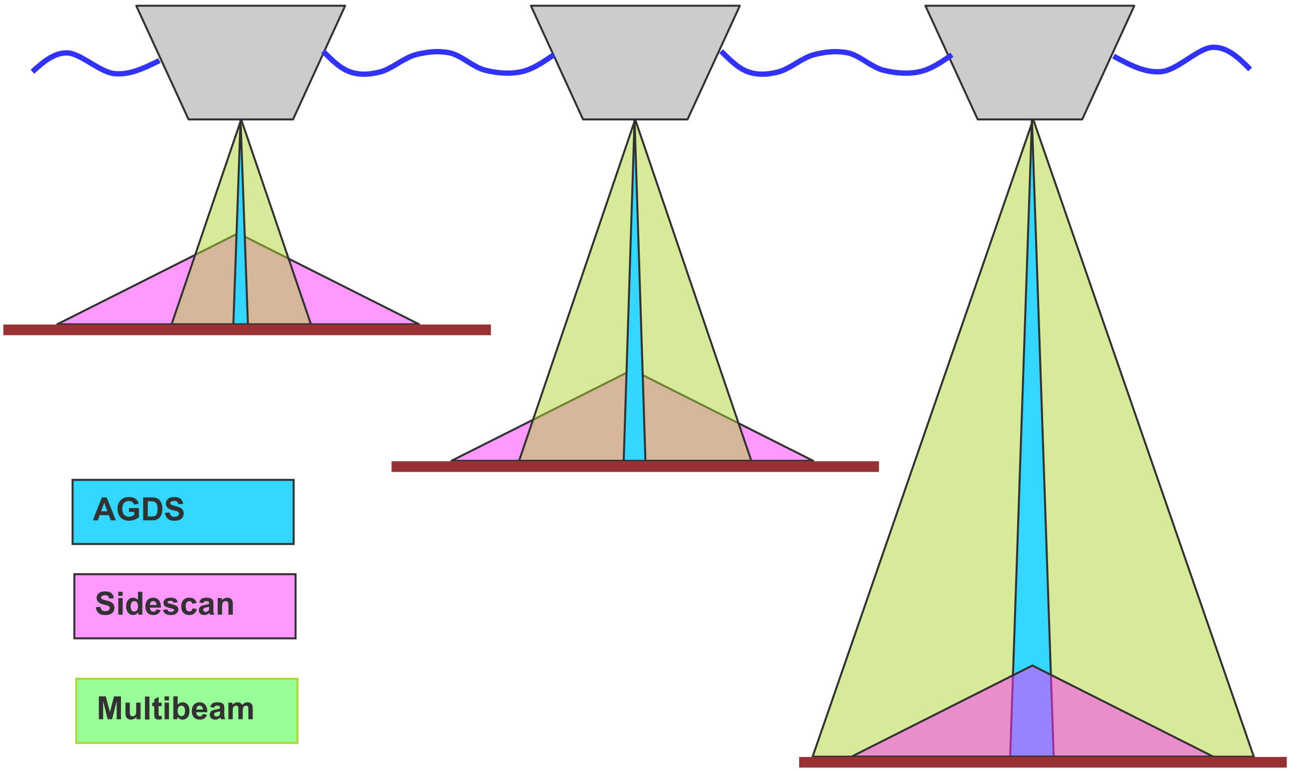
In some cases, the prime consideration in optimising a remote sensing survey is in how a technique can best be applied under the particular circumstances of the survey. This is particularly the case where 'standard' techniques are used at the limits of their application. For example, a sidescan sonar 'fish' is normally towed behind a survey vessel, but when used in shallow waters it can be pole-mounted and deployed over the side, stern or bow of the vessel. The position of deployment can have a significant effect on the functioning of the system and the quality of the data acquired, as demonstrated in the case study of shallow water sidescan surveys in the Dutch Wadden Sea Sidescan pole_Wadden Sea.pdf.

Further information on varieties and capabilities of remote sensing instruments are provided in the individual chapters of the MESH Review of Standards and Protocols for Seabed Habitat Mapping Review (Coggan *et al*., 2007).

Suites of acoustic techniques

Given a suitably equipped vessel, it is perfectly feasible to acquire data from multibeam, sidescan, seismic profiling and Acoustic Ground Discriminating Sonar (AGDS) systems all at the same time. Each of these systems can operate over a range of conditions (vessel speed, sea state, water depth), but their optimal operating conditions will differ. Consequently, if you run multiple systems at the same time, you should optimise conditions for the system you will rely on most, and accept that the other systems (and therefore the data they provide) may be sub-optimal.

The system that you select as your primary acoustic technique will have a major influence on the **track-spacing** of your survey lines. This is because the swathe width, or footprint, of acoustic systems is determined by the beam-angle and the height of the sensor above the seabed. In practical application, the footprint of hull-mounted systems (e.g. single beam and multibeam sonar) increases with depth, while that of towed systems (e.g. sidescan and interferometric sonar) is more-or-less constant, because the towed body is normally ‘flown’ at a fixed altitude above the seabed.



Footprint of three different acoustic survey systems relative to the depth of water (not to scale)

So, if you select multibeam as the primary technique, you will need a much closer track-spacing when surveying in shallow waters that in deeper waters, and it will take far longer to cover a given spatial area. This does not apply to towed systems, where the track spacing and rate of survey will be independent of water depth. Typical figures for the footprint of three acoustic techniques are given in the table below.

Typical swathe footprint of different acoustic survey systems, relative to depth					
Technique	**10 m**	**50 m**	**100 m**	**500 m**	**1000 m**
AGDS Fixed beam angle ~10^{o}	2 m	9 m	18 m	88 m	176 m
Multibeam sonar swathe ~ 7 times water depth	70 m	350	700 m	3500 m	7000 m
Sidescan sonar 400 m swathe at 6 m altitude	400 m	400m	400m	400 m	400m

When selecting a suite of acoustic techniques, AGDS systems are regarded as a secondary or tertiary choice, as their footprint is far smaller than the swathes achieved by multibeam or sidescan systems. The information they provide is complementary to that of the other systems and is valuable in helping to interpret sidescan or multibeam backscatter.

The track-spacing of survey lines is therefore usually dependant on the primary choice of multibeam or sidescan techniques. For a survey aiming to achieve 100%

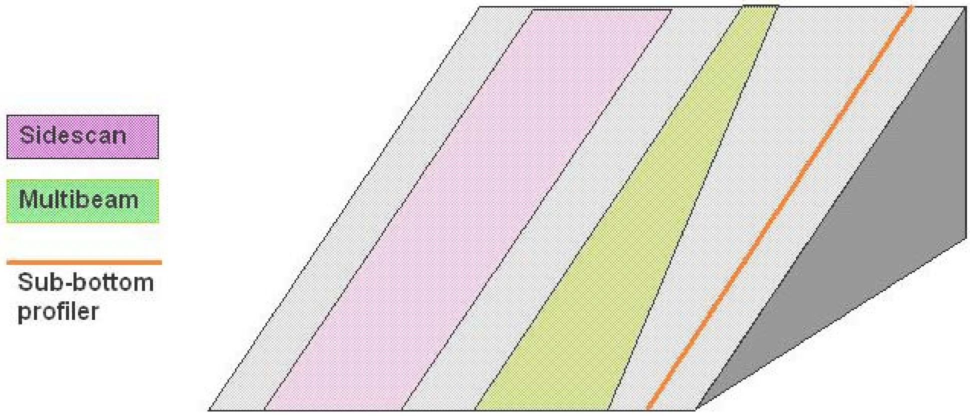
coverage, it is usual to set the track spacing so there is some overlap between the swathes of successive survey lines, as the quality of the data at the extremes of the swathe can be sub-optimal. Based on the figures presented in the table, a survey in 50 m water depth using sidescan and multibeam would require a track-spacing of 300 to 325 metres to achieve full coverage with both systems.. Surveys of shallower waters might favour sidescan as the primary techniques, due to the greater swathe, but as water depth increases the swathe of multibeam will begin to exceed that of sidescan, thus favouring multibeam as the primary technique. If full coverage is required by both techniques, then the survey will need to be conducted in two parts, the first using both techniques together and the second using only the technique with the narrower swathe to in-fill the spatial gaps in that data set. The reader is directed to the forthcoming ICES Co-operative Research Report on Acoustic Seabed Classification of Marine Physical and Biological Landscapes (Anderson *et al.*, in press) for detailed technical coverage of the subject, and specifically to the chapter by Simmonds (in press) on survey design for acoustic seabed classification.

It is becoming more common for multidisciplinary studies such as habitat mapping to include seismic profiling in the suite of ‘acoustic’ techniques used on survey, as vertical profiles through the sediments and/or substrata aid the interpretation of seabed morphology. Selecting the seismic profiling technique will depend on the expected stratigraphic sequence. Higher frequency systems such as boomer provide highest resolution (a few 10s of cms) but their penetration is limited with the acoustic basement (limit of penetration) being bedrock, glacial materials or even dense sand. Lower frequency systems such as sparker or airgun will have greater penetration but limited resolution (~1m). Their greater penetration may indicate the type of bedrock present rather than acoustic basement determined by a boomer system.

Profiling systems are usually surface or near surface devices towed in close proximity to the vessel. In deep water deep-towed boomer should be considered to obtain high-resolution information of the seabed and combined sidescan and profiler systems are available.

From a practical point of view running seismic profiling equipment simultaneously with sidescan sonar maximises the use of ship time as both operate best at similar vessel speeds (note: running sidescan with multibeam can restrict vessel speed). It allows integration of seabed feature thickness with their spatial geometry (e.g. thickness of sand waves). Accurate position logging of the towed device is important to enable results to be properly georeferenced and compared to information gained from hull-mounted devices such as multibeam or AGDS.

In some circumstances, the choice of acoustic technique may also influence the orientation of your survey lines. If the survey area has a significant slope, then running lines perpendicular to the slope will give variable swathe coverage for hull-mounted systems, but not towed systems. As the slope of the seabed becomes more severe, towed systems like sidescan will need more frequent adjustments to the amount of cable deployed in order to maintain the instrument at a constant altitude above the seabed. Such repeated adjustments are undesirable, as they tend to tend to interrupt continuity and diminish the utility of the sonar record. It is therefore usual to optimise the survey design by electing to run survey lines parallel to any slope in the seabed, which simplifies both the planning of the survey track-lines and the conduct of the survey, and reduces the risk of the towed devices contacting the seabed.

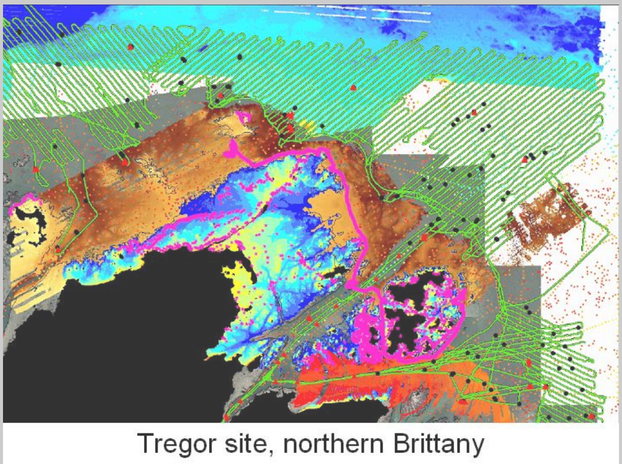


Swathe footprint of sidescan, multibeam and sub-bottom profiler lines when run perpendicular to a slope in the seabed.

It should be noted that habitat mapping tends to be relatively undemanding in its acoustic survey requirements compared to hydrographic/bathymetric surveys aimed at producing navigational charts or dealing with other issues relating to the 'Safety of Life At Sea' (SOLAS). These can require far greater coverage (200%, or 'double coverage') and must be conducted to meet strict surveys standards set by organisations such as the International Hydrographic Organisation (IHO) (see Mills,1998; resource file IHO survey standards.pdf and *How do I collect my data?*). Such standards usually exceed the requirements of a survey aimed purely at habitat mapping, but it is becoming more common to aspire to, or adopt, one of these standards as this provides some quality assurance for the survey data and eliminates the need to re-survey an area multiple times for different purposes.

Suites of airborne techniques

As with acoustic techniques, several airborne techniques can be brought together to make an effective suite of tools. This is best demonstrated by looking at a case study, such as that for the Tregor study site on the north coast of Brittany. This survey used a suite of four aerial techniques, namely satellite imagery, aerial photography, topographic LiDAR and hydrographic (bathymetric) LiDAR to map intertidal and shallow subtidal areas, and further complemented these data with shallow water acoustic surveys. The resource file Tregor survey strategy.ppt shows how all the various data layers fit together, and illustrates how the survey design has optimised the use of the various different techniques to target areas where they were most effective.



Tregor survey strategy.jpg

Slide show building up data layers from remote sensing surveys at Tregor, Brittany

As with acoustic surveys, issues relating to different swathe-widths and footprint sizes of the suite of instruments used in airborne surveys will influence the track-spacing of the flight path, but in aerial surveys there is generally more control over the selected altitude of survey.

As different instruments have different capabilities in detecting seabed features and habitats, using a suite of techniques will lead to a further requirement to inter-calibrate their outputs. This issue was examined in the MESH 'Intercalibration' workshop, which showed that cross-referencing the results from different techniques can be used to validate interpretations and can highlight some features that may be an artefact of a specific technique. Synergies may also be achieved by the combined interpretation of a number of different remote sensing techniques. The workshop focused mainly on a variety of techniques used to target sea grass habitats (*Zostera marina*) and is reported in the document Intercalibration Workshop Report.pdf .

Ground validation

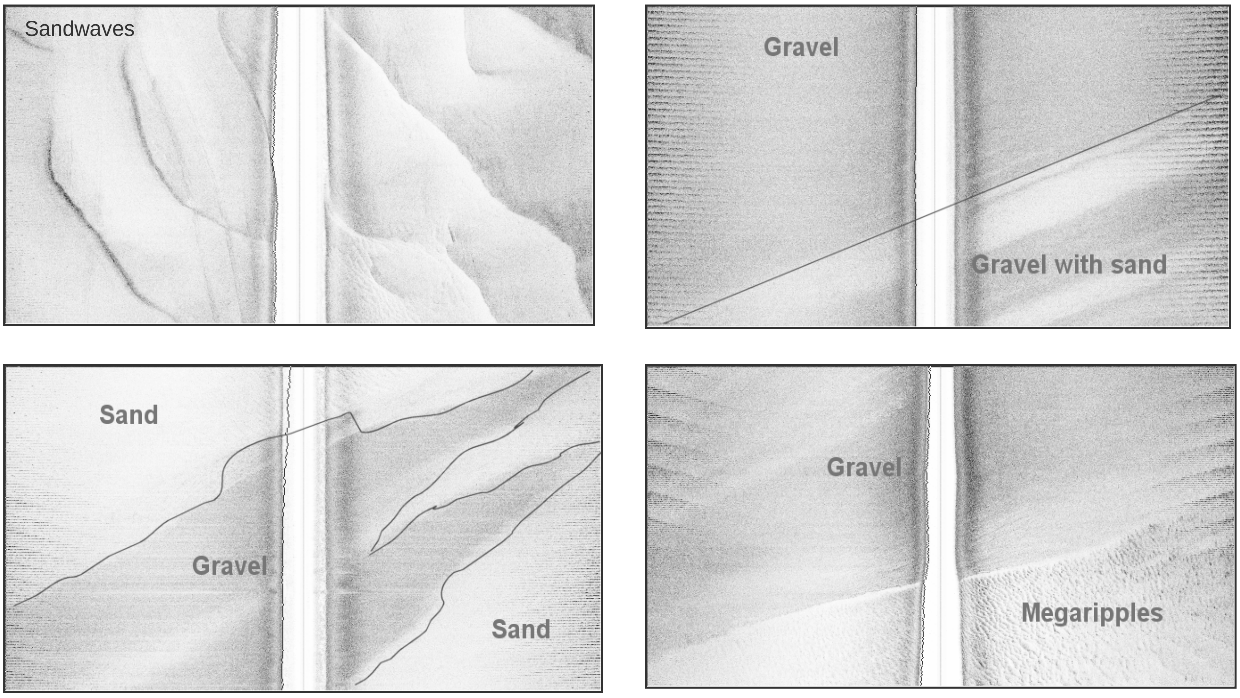
For those remote sensing techniques that are used principally to segment the surveyed area into different ground types (such as aerial photography, sidescan sonar, AGDS), it is good practice to collect some ground validation samples during the remote sensing survey in order to inform the segmentation process and 'validate' the resulting ground classes. Typically, ground validation samples are photographs of the seabed (particularly for hard substrates) or actual samples of the surficial sediments collected by a shallow digging device, such as a trowel or Shipek grab. The deeper sub-surface sediments are not required as these are not (usually) penetrated by the optical or acoustic sensing techniques. The process of ground validation is distinct from post-segmentation 'ground-truth' sampling, which will be more intensive and geared more towards sampling the biological components of the different ground types (including the sub-surface layers of softer substrata).

Ground validation is usually used post-hoc to help identify the ground type represented by a particular 'signature' in the remotely sensed data. An alternative is to run the remote sensing instrument over a series of known ground-types to see what signature each gives. This is frequently referred to as 'calibration'.

Aerial photographic surveys using the visible light spectrum usually require little or no ground validation on account of our familiarity with visible light imagery through our own observations. However, any hyperspectral imaging (e.g. infra-red photography) will likely result in images that are beyond our everyday experience and so will need ground validation to aid interpretation.

Comparison of visible spectrum (left) and infra-red (right) aerial photographs of shoreline features. There is a greater need for validation samples to interpret the infra-red image (green algae deposits in Saint-Michel-en-Grève, France).

In a similar way, acoustic images are usually beyond our everyday experience and will initially require ground validation until sufficient expertise has been developed to enable direct interpretation. The ground validation sampling should target acoustically distinct areas to help determine what ground-types they represent.



Sidescan sonar image illustrating acoustically distinct areas attributed to different ground-types.

Unlike sidescan images, the data from Acoustic Ground Discrimination Systems (AGDS – typically RoxAnn and QTC) cannot be interpreted directly with ease, even by experienced operators. AGDS systems discriminate substrata on the basis of their acoustic reflectance properties, and their outputs can be quite variable from day to day and even within a day depending on a wide range of factors such as vessel speed, state of tide, weather conditions, turbidity and depth. Some ground types even give variable responses depending on the direction a vessel travels over the seabed (Foster-Smith, 2007). Several approaches can be taken to standardising the data to remove such variability, including (a) comparing adjacent parallel survey tacks (b) run a few survey lines perpendicular to the main direction of survey, (c) run tracks over a known area with clearly defined ground types (so called ‘training sites’) at the start and finish of every day’s survey and (d) overlap some tracks from one day to the next. However, even after this standardisation, ground validation samples are needed to allow the post-hoc segmentation of the data into meaningful ground types (supervised classification – see Foster-Smith, 2007).

As with all sampling, it is important to provide representative rather than exhaustive samples.. Ideally, a minimum of three samples should be obtained per ground type, though Foster-Smith (2007) recommends five for AGDS surveys:

> “There should be at least 5 samples for each of the main habitats or biotopes. Even if the surveyor may feel that a particular ground type can be very confidently predicted (e.g., kelp forest in shallow water on hard ground) these habitats should still be sampled a minimum number of times. Failure to do this will compromise subsequent analysis.”

Links to resources:

[Sidescan pole_Wadden Sea.pdf]

[IHO survey standards.pdf]

[Tregor survey strategy.ppt]

Optimise the ground-truthing

The function of ground-truthing is to sample the physical and biological components of a particular ground type to enable it to be characterised as a habitat. Where an existing classification scheme is to be used (top-down classification) it is important to record the parameters relevant to that scheme, so the samples or observations can be matched with the appropriate habitat definition. Where an existing scheme is not available or not required, a variety of physical and biological parameters should be recorded consistently across the survey area to allow habitat classes to be determined, usually by statistical analysis (bottom-up classification).

Optimising the ground-truth survey is a matter of selecting the right sampling methods and directing their appropriate deployment to collect representative samples from the variety of ground types encountered in the survey area. The selection of sampling sites is guided by the knowledge gained from the remote sensing survey, and this ‘directed’ ground-truthing makes more efficient use of resources than a purely random placement of sampling sites.

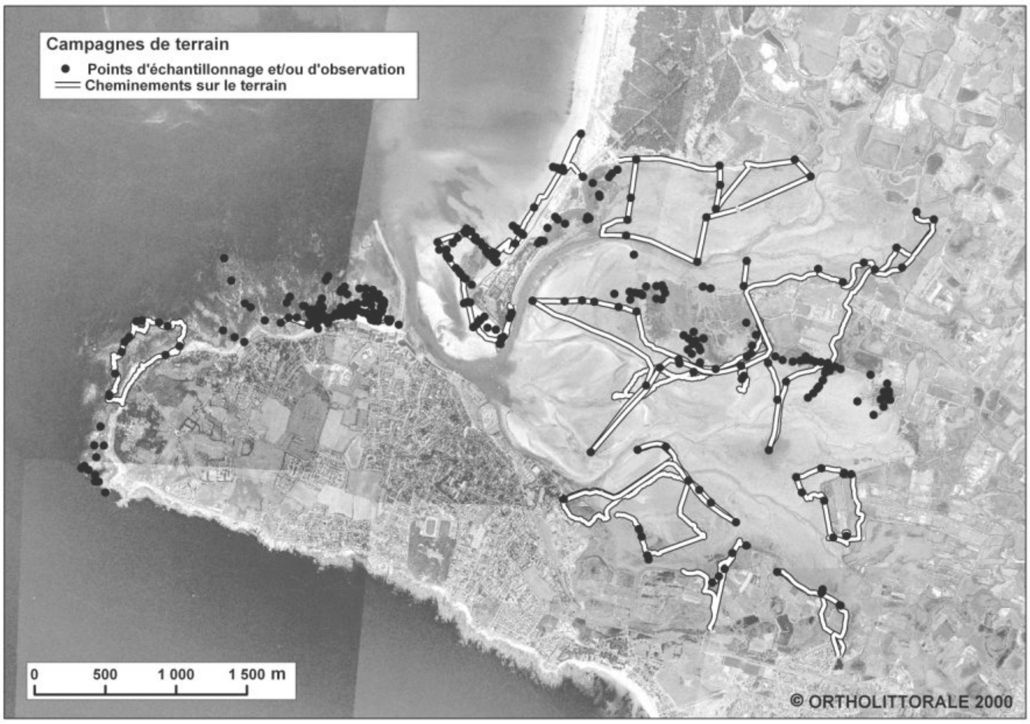
Trained human observers are powerful ground-truthing ‘tools’ due to their ability to recognise and classify habitats on sight. Where they have access to a survey area, such as on the shore or during diver surveys, they can intelligently explore the area, constantly taking visual ‘samples’ and directing other sampling effort where most needed. Their skills can still be used to good effect in deeper waters, though observing video or camera images and piloting Remote Operated Vehicles.

In deeper water, knowledge of what is actually on the seabed relies on the use of a variety of sampling devices. These are usually limited to grabs and corers, which sample sediments and their infauna, and trawls and dredges, which sample epifauna. Human observers can still play a part, through the use of video and stills cameras mounted on towed sledges, drop-frames or Remote Operated Vehicles (ROVs) but these only view the epifauna and surficial substrata. A combination of these sampling and observational methods is required to provide all the information needed to classify the habitats.

Sandy Shore_Brest.JPG HamonGrab02.jpg Beam trawl.jpg Camera sledge launch.jpg

Some ground truth sampling methods

Both ship-based and shore-based surveys should use the information available from remote sensing to help select sampling sites (a general location in which sampling will be undertaken), but the precise method of placing the sampling stations (a specific point at which a sample will be taken) may differ. On ship-based surveys, it is good practice to pre-plan a series of stations and specify which sampling gear(s) will be used at each one, so the vessel can plot an optimal route and arrive at each station fully prepared to deploy the gear. Stations may be selected to target specific features revealed by the remote sensing or to sample anywhere within a particular ground-type. The same can apply to shore-based or diver surveys, directing a person to go to a particular point to take a sample, but these surveys can be made more powerful by allowing the observer some flexibility to fine-tune the sampling design according to their visual assessment of the sampling site. They can decide what type of samples should be taken, how many are needed and precisely where they should be placed. In the special case of top-down classification, they may decide there is no need to collect samples if a habitat can clearly be identified by direct observation.



Location of sampling sites on a shore-based ground-truth survey in Brittany

It is important that sampling should be representative rather than exhaustive as it is easy to become overburdened with samples, which are both costly and time-consuming to process, analyse and interpret. To be representative, appropriate sampling techniques should be used on each ground type, but further stratification may also be needed to sample across relevant ecological zones (e.g. depth, salinity, turbidity) that are know to influence the distribution of species.

A minimum sampling requirement should be set, considering the level of classification accuracy and confidence required in the final map. Single sampling of each ground type forces the assumption that it is homogeneous. Replicate sampling allows some assessment of variability within and between different sampling strata (ground type + ecological zone). The number of replicates taken may be determined by a rule of thumb, expert judgement or some formal assessment linked to the heterogeneity/homogeneity of the ground as it appears to the remote sensing instrument (so called ‘Optimal Allocation Analysis’).

In many cases it will be necessary to set aside a proportion of the ground truth samples to test the accuracy of the map once it has been produced. The need for these 'validation' samples should be factored into the survey design.

Optimising the ground-truth survey design is often an iterative process, and it should remain flexible to a certain degree. A draft plan of the ground-truthing survey can be handed to those who will conduct the survey to check operational feasibility (access to sites, navigation hazards, Health & Safety matters, etc). However, the fine detail of the design frequently depends on the outcome of the remote sensing survey and the prevailing conditions at the time of sampling.

Ground-truthing requirements

The ground-truth survey should fulfil two roles. Firstly it should provide the biological and physical information required to determine or identify a habitat class. In general, so called 'direct' mapping exercises use ground-truth samples to assign a single habitat class to the ground-type and/or mapped polygon from which the samples were taken. It is not intended that the ground-truth sampling should greatly influence the segmentation of the survey area; its function is solely to determine the habitat class for areas that have already been mapped by direct interpretation of remote sampling images (aerial photographs or acoustic mosaics). In this way, direct mapping is akin to 'painting by numbers' as it imposes an attribute on a pre-defined area. However, in 'modelled' mapping, the initial segmentation of the survey area merely directs the placement of the ground-truth sampling effort. Once the samples have been collected the initial segmentation is discarded and an integrated analysis is made of the biological, physical and 'coverage' data (remote sensing and/or spatially modelled data) to produce a classified map. In this way, the ground-truth data influence both the classification and delineation of the habitats. In *How do I make a map?*, there are sections that give fuller accounts of these different approaches to mapping, but both require fundamental information on the physical nature of the substrate and the biological communities it supports, as detailed in the sections Physical information and Biological information in the current section *What do I want to map?*.

Secondly, ground-truth surveys provide the opportunity to verify the validity, nature and location of any of the putative borders between ground-types, segments or habitats that have been determined prior to the survey, and this requires some form of observational sampling. For both vector and raster type maps, checks should be made that the borders relate to real habitat changes on the ground rather than artefacts of the remotely sensed data or the mode of its interpretation. Patchy cloud cover can cause differential shading on aerial photographs and changes in slope may cause similar shading in sidescan images, but neither reflects a real change in habitat type on the ground. The very act of mosaicing images can also introduce false 'shade' borders (see the orthophotographs in the previous section Optimise the ground-truthing). Where an image shows a gradation from one ground type to another, ground observation can help to determine the appropriate placement and type of border (discrete or transitional) between different habitats.

Sampling effort

The amount of ground truthing effort required is influenced by several factors including, the heterogeneity of the study area, the required degree of confidence in the map and the level of detail required in the habitat classification.

Clearly a heterogeneous area with more ground types will need more sampling than a homogeneous area with few ground types. Also, if a ground type itself is found to be heterogeneous (i.e. a mixed substrate) then this will need more sampling effort to determine the range of habitats it contains (see also 'Optimal Allocation Analysis' below).

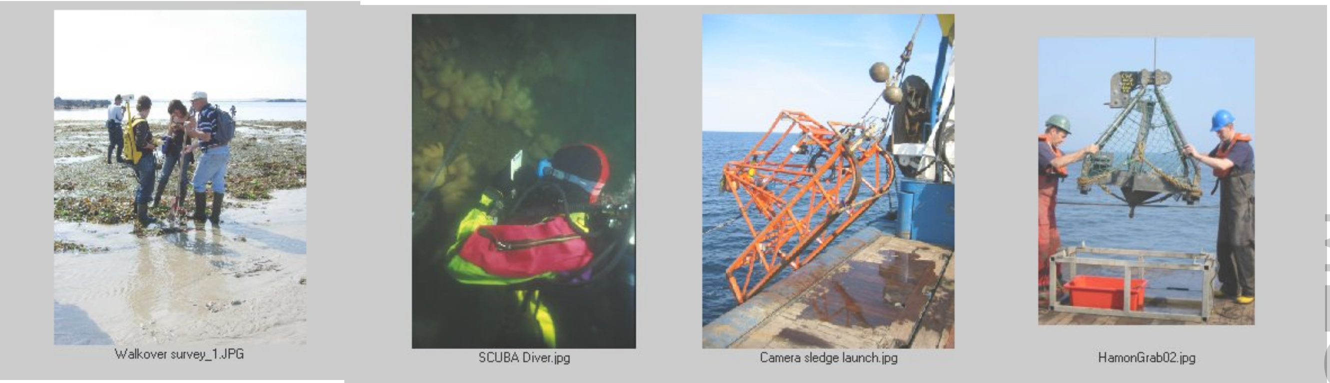
More samples tend to increase confidence in a map, as they reduce uncertainty in classification accuracy. Assigning a habitat class on the basis of a single sample will be less certain than assigning one based on, say, five samples that all show the same characteristics. Consequently, greater sampling density is needed in studies that require high levels of confidence in the mapped output. Four basic sampling regimes have been discussed earlier in the section Ground-truth survey strategy, and *How good is my Map?* explains more about assessing confidence in maps.

It is the nature of hierarchical classification systems to use different types of information at different levels of the classification, so the more precise the classification, the more information is required (see the earlier summary table of EUNIS levels 3, 4 & 5). Some levels in the hierarchy require only physical information while others require both physical and biological information, which may lead to additional sampling requirement. However, if one level merely requires more detail than its predecessor (e.g. identifying organisms to species rather than Family level), this can be satisfied by more detailed analysis of existing samples.

Biological assemblages comprise both infuana and epifauna (and flora) and both must be sampled to provide a complete description of the habitat. A single sampling event or device is rarely adequate for sampling both faunal fractions, so it is normal to sample each fraction separately using gear and protocols specifically designed for the job (see *How do I collect my data?*).

Directed ground-truthing.

Ground-truth techniques can differ greatly between inter-tidal and sub-tidal studies. Direct human observation is a particularly effective ground–truthing method and is most often used in inter-tidal studies where sampling sites are easily accessible. Each observer effectively takes thousands of visual 'samples' over a wide range of spatial scales and can make a very rapid assessment of the shore in relation to the remote survey map (e.g. an aerial photo) and can direct sampling effort (*ad hoc*) to those areas where it is most needed. A single 'walk-over' survey may be all that is required to effectively ground-truth the remote survey data. In shallow sub-tidal areas, divers can make similarly effective direct observations, though the areas they can cover are limited by mobility and visibility under water.



Examples of a variety of ground-truth techniques. Left to right: Walk-over surveys of the shore, diver surveys in shallow waters, video surveys, grab sampling. (photo credits: 1 & 2 JNCC, 3 & 4 Cefas)

For the deeper sub-tidal areas (usually sites away from the shore) ground truthing is often wholly reliant on using a variety of remote sampling devices such as grabs, trawls and video/stills cameras, the selection of which is discussed in Selecting a suite of tools. As sampling effort can no longer be directed *ad hoc* by our own observations we must rely on some *a priori* rules to determine sampling frequency. These are discussed further in the section on Ground-truth Survey Design.

Number of samples

Ground-truth sampling is a critical step in classifying habitats and needs to be effective but not over-burdening. The prospect of being over-burdened with samples relates to the number of samples obtained and the manner in which they are analysed. Given that acquiring samples is often the most costly part of a ground-truth survey, it would seem appropriate to ensure that each sample is thoroughly processed in order to obtain maximum long-term benefit. Detailed information can always be aggregated to suit the purpose of broadscale mapping, but the converse is not true; fine detail cannot be derived from ‘superficial’ data. In the long term it is more cost efficient to ensure that the data is collected once and used many times, rather than having to repeat sampling to satisfy different data needs.

The strategic selection of a suite of sampling techniques can reduce the overall sampling effort needed for ground-truth surveys, as many techniques provide both physical and biological information. For example, grab samples can provide information on both the nature of sediments and the composition of the biota they support. It is important to consider both the complementarity of sampling sites and sampling techniques when designing the ground-truth survey. Further details are given in the sections Selecting a suite of tools and Ground-truth Survey Design.

Peripheral information

Gound-truth surveys may also provide an opportunity to collect environmental data or information (observations) that are used as categorical descriptors of habitats, such as salinity, tidal stream and wave exposure (see table). Precise measurement of variables (e.g. tidal stream) is not usually required and the quoted bounds of the categories (e.g. “strong tides” as 1.5 to 3.0 m per second) should be regarded as a guide rather than being definitive.

Categorical descriptors of environmental conditions of major

relevance in determining habitat classes in the littoral, infralittoral and circalittoral zones.		
Salinity (parts / 1000)	**Tidal stream (knots) (m / second)**	**Wave Exposure (category)**
Low (<18)	Very weak ((negligible))	Extremely sheltered
Reduced (18-30)	Weak (< 1) (<0.5)	Very sheltered
Full (30–35)	Moderate (1-3) (0.5 – 1.5)	Sheltered
Variable (18↔35)	Strong (3-6) (1.5 – 3)	Moderately sheltered
	Very strong (>6) (>3)	Exposed
		Very exposed
		Extremely exposed

Physical information

Ground-truth sampling should aim to provide information on the geophysical properties of the seabed substrata as these have a great influence on the types of organism the substrata can support. It is wise to determine precisely what type of physical information is needed from the ground truth samples as this will indicate if a rudimentary analysis will suffice or whether a detailed (and far more time consuming and costly) analysis is required.

For sediments, this may require some form of granulometric analysis to determine the particle size distribution ('particle' or 'grain' size analysis), which indicates not only the type of particles present (mud, sand, gravel etc) but also how uniform or mixed the sediments may be (e.g. sandy gravel, muddy, gravelly sand). Some analysis of the physical and chemical characteristics of sediments may also be desired (e.g. compactness, shear strength, porosity, depth profile of oxygen content etc). The proportion of organic material (e.g. shell fragments) can also influence the suitability of a substrate as a habitat for a particular organism. Accounts of granulometry and geophysical analyses are given in the MESH_Standards_&_Protocols_2nd_Edition_26-2-07.pdf Coggan et al., 2007). It should be noted that detailed sediment analyses are both time consuming and costly and can provide information far in excess of the detail required by some habitat classification systems.

Hamon grab sample1.JPG

Dry sieve shaker.jpg

Wet sieving.jpg

Determining particle size distribution for a sediment sample (left) using dry sieving (centre) and wet sieving (right) techniques. (photos by Cefas)

For hard substrates (rock, boulder, cobble) a lithological interpretation may be useful as different rock types have different physical properties (e.g. hardness, friability) and these influence the types of organisms that colonise them (e.g. burrowing organisms prefer softer rock types).

For some classification systems, a more generalised description may be all that is necessary, providing a general indication of the main substrate and sediment types (e.g. cobble, granule, sandy gravel, muddy sand etc). There are several classification systems for describing sediment types and the table here compares the three most frequently encountered in European habitat mapping studies, namely the Folk, Wentworth and MNCR classifications. The EUNIS classification system does use the MNCR terms listed here, but at some levels it employs poorly defined terms such as ‘mixed’ or ‘coarse’ sediments that can easily be determined from visual observation alone.

Sediment Classification Systems: MNCR, Wentworth and Folk

phi value	mm	Size Class: MNCR		Size Class: Wentworth		Size Class: Folk
		Boulder		Boulder		Gravel
-8	256	Cobble		Cobble		
-6	64	Pebble		Pebble		
-4	16	Gravel				
-2	4	Coarse	Sand	Granule		
-1	2			Very coarse	Sand	Sand
-0.5	1.41					
0	1	Medium		Coarse		
0.5	0.71					
1	0.5			Medium		
1.5	0.35					
2	0.25	Fine		Fine		
2.5	0.17					
3	0.125			Very Fine		
3.5	0.088					
4	0.0625	Mud		Silt		Mud

Biological information

The biological information required from the ground-truth survey depends largely on the scope of the mapping project. Some may use only the broader habitat descriptions and may require no biological information at all. Some may be satisfied by very general descriptions of the biota, using life-form categories such as 'kelp park' or '*Zostera* beds' which can usually be identified by observation alone. Others may need fully quantitative sampling to identify the habitats at the fine scale end of existing classification systems (e.g. EUNIS levels 5 and 6) or to enable a robust statistical analysis to differentiate communities according to their species composition. The amount of detail required should be established from the scoping report and survey specification.

For the purpose of habitat mapping, biological information is limited to the macrofauna and macroflora. Macroflora are restricted to the photic zone and are usually attached to a substrate. Macrofauna occur in all depth ranges and may be infaunal (living in the substrate) epifaunal (living on the substrate), sessile or motile. This has consequences for the design of the ground-truth survey, as there is no single way of effectively sampling all these faunal elements. Some are more amenable to sampling (or recording) than others, with a result that existing habitat classification schemes can be biased towards infauna in one part of the classification and epifauna in another. Consequently, a good working knowledge is required of existing schemes to ensure that the ground-truth survey delivers appropriate biological information.

Where the mapping programme calls for actual sampling (as opposed to just observation) the goal is to enable the community composition to be described in terms of the species present and their relative abundance, which may be determined by fully quantitative or semi-quantitative means. Fully quantitative measures are provided by abundance (i.e. the number of individuals of each species present) or biomass (the total weight of each species present). It is often advisable to record both so that colonial and encrusting organisms that do not lend themselves to abundance counts (as they do not exist as 'individuals) are not omitted from the observations. Abundance and biomass are most frequently used where actual samples of organisms have been obtained, as in grab or trawl sampling. It is convention to express relative abundance as numbers per unit area of seabed sampled, even for grab and core samples that may return different volumes of sediment on each deployment.

Semi-quantitative measures are provided by scoring the presence of each species according to a scale of relative abundance, such as the 'SACFOR' scale (see table below) developed for marine habitat studies under the UK's Marine Nature Conservation Review (MNCR) programme (for further details on its application see http://www.jncc.gov.uk/page-2684).

Such scales are most appropriate where communities are observed *in-situ*, such as on beach surveys or where divers or underwater video/photography have been used. They are particularly useful in habitats where the characterising fauna/flora are attached to a substrate (e.g. rock outcrops) and are not amenable to fully quantitative measures of abundance and biomass. Instead, the relative abundance is assessed according to the percentage cover or density of a species within a given area (e.g. 1 square metre).

'SACFOR' scale of relative abundance	
Code letter	**Meaning**
S	Super abundant
A	Abundant
C	Common
F	Frequent
O	Occasional


Kelp forest 61.JPG

R	Rare

Selecting a suite of tools

Some mapping studies call for information that is beyond the scope of direct observation, either because all or part of the area is not directly accessible (e.g. sublittoral habitats) or because some form of quantitative data are needed to provide detailed information on the community composition and nature of the sediment. In these circumstances, the ground-truth survey must resort to using sampling devices (tools) to collect material for analysis. As no single sampling device can effectively sample all different types of substrata and biota, it is necessary to select a suite of sampling tools.

The variety of tools most commonly used for benthic sampling is tabulated below and has been introduced earlier under the section Ground-truthing Techniques.

Generic techniques for benthic sampling and varieties of specific tools	
Technique	**Variations**
Grabs	Hamon, Day, Smith-McIntyre, Van Veen, Shipek,
Corers	Box, Nioz, Vibrocore, Mutli-corer
Trawls	Agassiz, Beam, Otter
Dredges	Oyster, Scallop, Naturalist, Rallier du Batty, Rock, Anchor
Video & photographic	Towed or drop-frame cameras. Remote operated vehicles (ROV's). Sediment Profile Imagery (SPI)

The importance of selecting techniques that are suited to the anticipated survey conditions (e.g. depth, sea state, substrate type, turbidity etc) has also been discussed previously in the section Suitability of survey tools. If a generic technique is suitable, consideration should now be given to which of the various designs of tool within that technique will be most useful. Designs tend to propagate because a single design is not suitable under all circumstances. For example, the twin-bucket grab designs of Day, Smith-McIntyre and Van Veen are all prone to fail when used on coarse substrates as stones get trapped in the jaws preventing them from closing and capturing a sample. The Hamon grab is more effective on coarse substrates as it has a single bucket that operates in a ‘scoop’ rather than a ‘scissor action. For detailed accounts of the variety of tools available and their capabilities and limitations, the reader is directed to the MESH_Standards_&_Protocols_2nd Edition_26-2-07.pdf (Coggan et al. 2007).

The selection of tools must also be matched to the capabilities of the vessel from which they will be deployed. Clearly the vessels must be capable of safely deploying and recovering the gear, but vessel control during deployment is also a consideration. Camera gears often require a vessel to make headway and maintain steerage at very slow speeds (~0.5 knots) and larger ROV's may require dedicated winch cables and power supplies.

In most cases where sampling is carried out from a vessel, at least two faunal sampling techniques will be required at each ground-truth station, one to sample the infauna (e.g. grab or core) and one to sample the epifauna (e.g. trawl or dredge). In sub-tidal habitats, visual techniques (diver or camera surveys) may also be needed to sample those organisms, such as encrusting or attached fauna, that are not amenable to the other sampling techniques. In inter-tidal areas, direct visual sampling is usually sufficient to determine the macro-flora and epifauna, but samples will need to be taken of the sediments in order to determine the infauna. In some cases, quantitative samples may be taken of the inter-tidal epifaunal communities if they cannot be readily studied in-situ.

Biological sampling on intertidal mud flats (left) using visual sampling for epifauna and a large hand-operated corer for infuana. In deeper waters, visual techniques may be required to sample attached and encrusting epifauna (centre) and grabs or cores to sample infauna (right). (photos by Alterra, Cefas, JNCC))

The need to sample a range of substrates from mud to rock for sessile and motile organisms that live on or in the sediments can lead to the perceived need for a bewildering variety of sampling tools and an exhaustive sampling campaign. This should not be the case. Clearly some sampling techniques will be able to provide information that is relevant to both the physical and biological aspects of the habitat, for example, grabs will provide samples that can be used to describe the sediment type and the infuana, while underwater video may give information on both the surficial sediments and the epifauna. The ground-truth survey can be optimised by the judicial selection of a few tools that provide multiple types of information, as explained in the following section Complementary ground-sampling techniques.

Complementary ground-sampling techniques

Several references have been made to the need to select complementary sampling techniques in order to optimise the ground-truth survey. Here we present the concept that you will need to examine the capabilities of the various generic sampling techniques against the type of information or samples that your ground-truthing survey is trying to obtain. This part of the MESH Guide is specifically aimed at guiding you towards the questions you need to address rather than providing "an answer". As all surveys will be conducted under slightly different circumstances, it would be inappropriate to make specific recommendations here, other than in the broadest terms.

The table below assesses a number of generic sampling techniques against the types of information required from a ground-truth survey. Cells are coloured green where the techniques are applicable, and pink where they are not. Green cells contain a score indicating the relative efficacy of the technique:

3 = fully effective (or quantitative)

2 = moderately effective (or semi-quantitative)

1 = partly effective (or qualitative)

The idea is to select a suite of methods that provide the most effective overall sampling. The scores should be used in an additive way along the rows, with the aim of reaching but not greatly exceeding, a score of 3 (fully effective). The example here relates to sub-tidal surveys on mixed sediments (NB. The divers are assumed to be recording visual observations only, i.e. they are not equipped with other sampling devices).

Ground-truth requirements	**Generic sampling techniques**						
	Grabs	Corers	Sediment Profile Imagery	Trawls	Divers	Video	Stills camera
Describe bedforms					2	2	
Describe substrates	3	3	3		2	2	2
Particle size analysis	3	3	2				
Geotechnical measures		3	1				
Examine sediment profile		3	3		1		
Detect habitat borders					3	3	
Sample epifauna				2	1	1	1
Sample infauna	3	3			1		

To sample both infauna and epifauna, some combination of grabs/corers plus trawls and an observation technique (divers, video, stills) is required. Neither trawls or the observation techniques are not fully effective at sampling epifauna, but a combination of the two would appear to be highly beneficial. Coupled with grabs they make an effective suite for sampling the coarser sediments, where corers tend not to be effective. In softer sediments, the preference would be to substitute the grab for a large coring device, such as a box corer or a NIOZ core.

There is little to be gained from using both corers and Sediment Profile Imagery (SPI), as all the information provided by the SPI can be provided by corers, sometimes more effectively. However, if corers were unavailable, the SPI would be a reasonable substitute, when combined with grabs.

Obviously some techniques are not applicable under certain conditions, such as video cameras in turbid water, grabs or corers on rock substrates, etc. Some specific tools may be more effective than others, but that benefit may have severe cost implications (e.g. using an ROV in preference to a drop-camera). The selection of a suite of sampling tools clearly has to be informed by knowledge of the circumstances of the survey and the conditions under which they will be used. It is however true that the more the selected techniques complement each other, the more effective the survey will be.

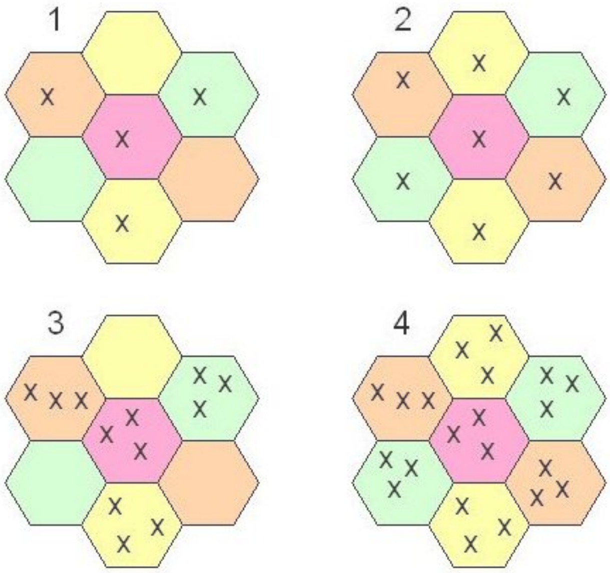
Ground-truth Survey Design

SECTION UNDER REVISION

There are different considerations for the design of ground truth surveys for intertidal and sub-tidal regions, largely because it is easy to access the intertidal area and this allows an adaptive survey design where decisions about precisely where and what to sample can be made in the field. On ship-based subtidal ground-truth surveys there is far less flexibility as the vessel needs to be directed to a pre-determined location to collect one or more samples using a pre-selected set of sampling tools. These points are illustrated in the subsequent sections on Intertidal surveys and Subtidal surveys, but in this section we will focus more on generic considerations that may be applicable to both intertidal and subtidal surveys.

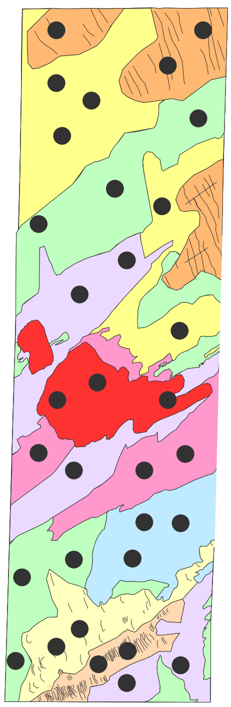
Representative sampling

As has been mentioned previously, sampling should be representative rather than exhaustive. To be representative, the sampling design should ensure that all the different ground types are covered and that each ground type has a similar amount of sampling. This is particularly important where the sample data are subsequently used in any form of statistical analysis (e.g. cluster analysis or supervised classification of remotely sensed data) to minimise the effects of sampling bias. The earlier section dealing with the ground-truth survey strategy showed four strategies which each gave a balanced survey design. The section also dealt with the need to stratify the sampling across strong environmental gradients (e.g. depth, salinity, current speed, wave exposure) and across recognised biological zones (littoral, infralittoral, circalittoral etc).



Examples of four sampling strategies that give a balanced design for ground-truth surveys, helping to ensure representative sampling of each ground-type.

The strategy selected depends on the scope and purpose of the mapping project, the first example being more suited to broadscale mapping providing summary information and the fourth to finescale mapping for monitoring purposes. If funding allows, something similar to the fourth strategy (many samples from every area) may be selected for a broadscale map that requires greater certainty than can be provided by option 1 (few samples from every ground type). The selected strategy is now imposed on the segmentation of the survey area produced by the remote sensing survey to provide the basic survey design, as illustrated below.



Example of a sampling strategy applied to a segmented survey area.

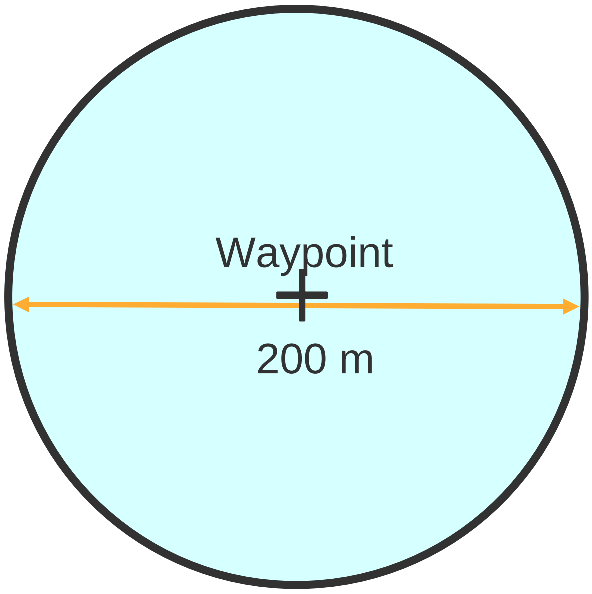
The sampling effort is directed to target the different ground types with a (relatively) equitable sampling effort in each. Each point on the diagram represents a sampling site, defined as a general location in which sampling will be undertaken. The sampling sites are spaced across each ground type in a random or haphazard fashion to minimise the effects of spatial autocorrelation; samples taken close together are likely to be more similar than those taken far apart (i.e. sample similarity is inversely related to distance between sampling sites). Where the remote sensing provides some detail of features within a mapped polygon, such as a large sand waves within a sand wave field, it may be desirable to position sampling points to target specific parts of that feature such as the crests or troughs of the waves.

Sampling sites and stations

The difference between a sampling site and a sampling station is most easily understood if you consider that a site is a general location where you plan to take a sample, and a station is the actual position where you eventually took the sample. Hence, a sampling site is a proposed sampling location whereas a sampling station is a recorded sampling location. The distinction is important because you may arrive at a site and find that the location you have been given is unsuitable for sampling; maybe it is occupied by some other person (or vessel) or by chance there is a patch of hard ground at the point you attempt to take a grab sample. In both cases you need to move away from the planned position in order to collect the desired sample. It is important to record the actual sampling position rather than the planned sampling position (if they differ), especially if you need to return there to take more samples for monitoring purposes.

In the intertidal region, the survey sites may be given as a list of features that need to be sampled, such as a beach or a rock outcrop and it is left to the field-survey team to reconnoitre the site to decide where it is best to sample. Alternatively the plan may provide specific positions that need to be sampled, such as a transect across a salt marsh.

In subtidal surveys it is normal to plan sampling sites as specific waypoints to which the support vessel must navigate, but it is impractical to expect the vessel to come to a halt or to be able to maintain station at the precise location given by the waypoint. Instead, it is practical to consider the waypoint as the central point of a 'bullring' within which the sample should be taken. The waypoint and bullring therefore define the sampling site.



Waypoint and 200 metre diameter bullring sampling site.

This arrangement proves very practical for offshore work as the vessel merely has to ensure it remain within the bullring during grab sampling and can tow trawls and video sledges across the ring in any direction that suits the prevailing tide and wind conditions. The diameter of the bullring can be adjusted to increase or relax the spatial precision, as required. For unsophisticated vessels, the waypoint can be recorded as the location of the sampling station and qualified by a measure of spatial accuracy (such as ± 100 m for a 200 m diameter bullring). For more advanced vessels the position of each sampling event (point or line) within the bullring can be recorded using GPS fixes corrected for known or measured offsets (i.e. the distance from the sampling gear to the GPS antenna). There is also scientific value in knowing that samples of the infauna, epifauna and substrates all originated from a defined area and can be considered representative of the same habitat (with the obvious corollary that the habitat is assume or demonstrated to be uniform across the bullring).

Sample replication

One of the most difficult tasks of the survey design is to determine how many replicate samples are needed to provide representative coverage of a ground type. If the basic survey strategy has decreed one sampling station per ground type or per segmented area (mapped polygon), there can be little argument beyond which is the best combination of sampling tools to use given the funds available. However, where there is an allowance to take multiple samples, it can be a complex task to apportion the available sampling effort in the most beneficial manner, as there are so many variables to consider.

The first stage is to consider the variety of ground types that must be sampled and the suite of tools that have been selected (as discussed earlier). The second is to consider the information they need to deliver (also discussed earlier) and the third is to consider what can practically be achieved within the resources available (time, budget, equipment, personnel). It is then useful to start with some simple rules-of-thumb and work from these up into a more complex design.

The first rule you can set relates to a minimum sampling requirement. The whole point of using sample replication within a ground type or polygon is to test the assumption that the ground or area is homogeneous. A single sample forces this assumption and does not allow any testing, Two samples can theoretically provide a 'yes' or 'no' answer, but in practice no two samples taken from the benthic marine habitats are never likely to be identical (exactly the same sediment and species composition), so two samples are of little practical use, except where expert judgement is used. This is essentially testing the two samples against many 'virtual samples' that collectively provide the experience of the expert. It is only when a minimum of three real samples is available that the degree or heterogeneity/homogeneity can formally be assessed, using univariate indices of dispersion (mean, variance, skewness etc) to describe the variability among the samples. Such statistics are rarely quoted in the context of habitat mapping but form the basis of our subjective assessment. It is, however, likely that that they will find increasing use to indicate the degree of confidence that can be placed in a map.

The first rule-of-thumb is therefore that a minimum of three samples is required whenever sample replication us used in the survey design.

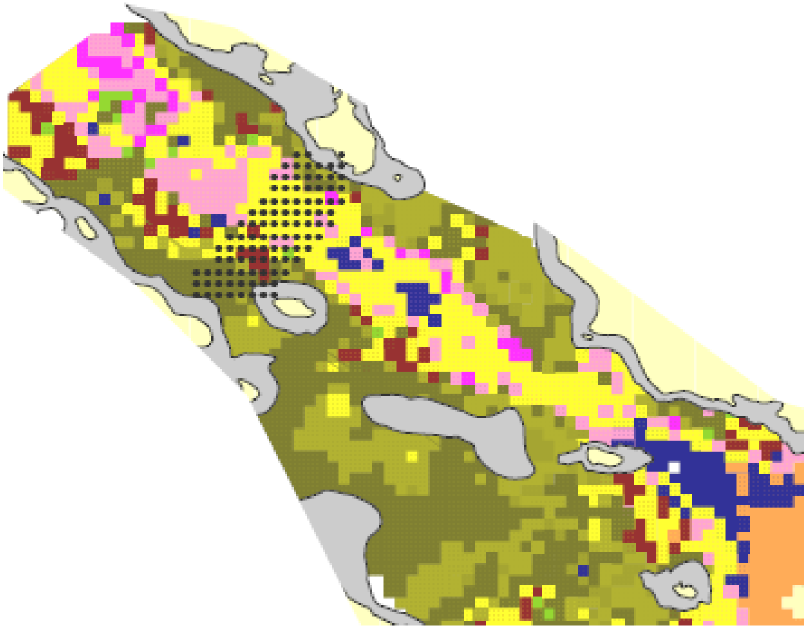
The second rule considers the need to maintain representative sampling as the size of the 'homogeneous' area increases. An increase in area means there is a greater likelihood of a difference in habitat, so the number of samples taken should increase in proportion to the size of the area. Here, you can set your own rule-of-thumb depending on the perceived need and the circumstances of the survey. The example given in the table has been used in intermediate scale surveys of offshore sand and gravel substrates in the English Channel and North Sea. Starting with a minimum of three sampling sites in any 'homogeneous' area <= 1 km^2, the sampling frequency is increases by one site for each additional square kilometre. (see also Subtidal ground-truth surveys)

Basic 'rule-of-thumb' for sampling homogeneous areas in offshore benthic surveys

Size of area	Sampling frequency
< 1km^2	3
1 to 2 km^2	4
2 to 3 km^2	5
3 to 4 km^2	6
4 to 5 km^2	7
Etc	etc

These basic rules hep to set out the minimum number of sampling sites, but clearly they are not applicable for all situations. Modifications will be needed for highly heterogeneous areas such as narrow shorelines or extremely large offshore expanses of a single ground type.

A less simple scenario is where the remote sensing survey has resulted in a complex segmentation of the survey area, which can be typical of the raster-style maps produced by AGDS techniques (see diagram). Here it would be impractical to sample every 'polygon', so ground-truth sampling is aimed at representatively sampling every ground type. Foster-Smith (2007) recommends that each ground type should be sampled at least five times.



Example of raster-style segmentation of a study area by AGDS, with different colours indicating different ground-types.

Statistical methods can provide a more objective approach to determining the number of samples required to characterise a ground type, and a technique called **Optimal Allocation Analysis (OAA)** has been investigated by the MESH project. In principle, the concepts are simple:

- The more heterogeneous a ground type, the more samples will be required to characterise it.
- To maintain representative sampling, sample frequency should increase as the area to be sampled increases.
- A greater number of samples provide greater statistical precision in determining variability.

So, the number of samples required depends on the heterogeneity of the ground type, its spatial area and the desired statistical precision. Heterogeneity can be assessed from a number of modern remote sensing techniques that produce digital data. For example digital sidescan sonar images comprise a mosaic of grey-scale pixels, and as each pixel has a grey-scale value, the heterogeneity within any area defined as a 'ground-type' can be described mathematically using basic statistics (mean, variance etc). The variability detected by remote sensing is used as a proxy for habitat heterogeneity and the Optimum Allocation Analysis uses statistical measure of this variability to calculate the number (n) of samples required to adequately represent the area and account for, say, V% of the variability. A simple algebraic re-arrangement of the equations can be used to calculate the V% figure if you know you are limited (possibly by budget) to a fixed number (n) of samples. The application of Optimal Allocation Analysis in habitat mapping is in its early stages but it has obvious implications for the design (and cost) of ground-truth surveys. A more comprehensive explanation is provided in conjunction with a pilot case study in the document OAA worked example v1.doc .One of the great advantages of a hierarchical habitat classification system is that a habitat class can always be assigned to an area. For example, if all the samples from an area showed it was a fine sand ground type, then it can be classed as 'fine sand', but if some samples showed it was fine sand and other showed it was coarse sand, a less precise but still accurate classification of 'sand' could be used.

Intertidal surveys

The intertidal ground-truth survey has two aims, to validate and ground-truth the remote sensing survey.

The validation is required to check both horizontal and vertical accuracy of the Digital Terrain Model (DTM) using dGPS RTK (Real Time Kinematic) ground surveys of reference sites and conspicuous objects selected from (aerial) orthophotographs. This can be done at any state of the tide as the reference sites are usually located in the upper reaches of the tidal zone or on dry land. The procedure is explained in the Case Study Validating the digital terrain model.doc

An initial interpretation of the remotely sensed data (satellite imagery, aerial photographs, LIDAR etc) is made using unsupervised classification or manual contouring to identify different facies and their borders, which are represented on a draft physical map. Borders may be distinct, or gradual transitions from one facies type to another.

The ground-truth survey is then planned to target different facies and borders, using a series of transects and point sample locations. The majority of surveying will use direct observation, noting the nature of the substrates and the communities they support. Quantitative sampling should be undertaken at a selection of sites representing distinct facies types to provide detailed information on the community composition and nature of the sediments (through granulometric analyses).

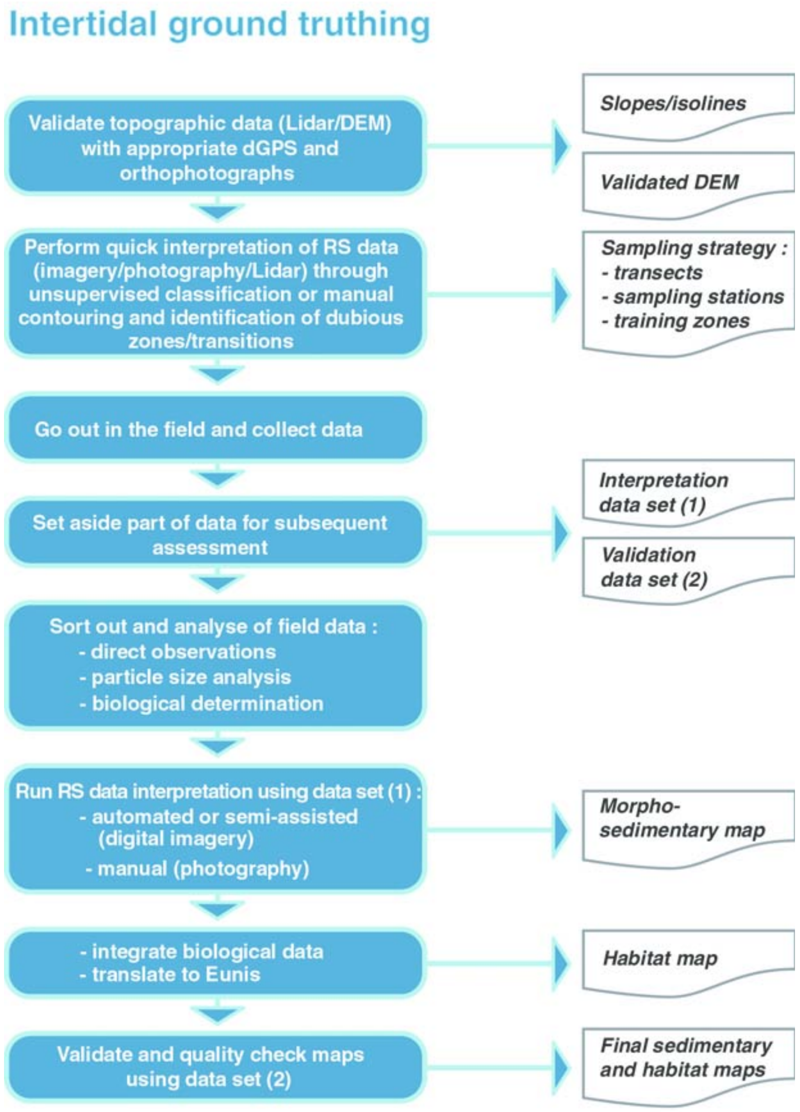
Intertidal ground-truth sampling sites and transects overlain on an orthophotograph at a study site in le Croisic, Brittany.

If automated interpretation and classification techniques are to be used to analyse the remotely-sensed data, then care must be taken to adequately sample locations that will be used as 'training zones' in supervised classification. Sufficient samples and observations should be collected to allow the resulting data to be divided into two parts, one data set being used to make the interpretation (i.e. to define 'signatures' to be used in the supervised classification) and the other to subsequently validate that interpretation.

Unlike sub-tidal ground truth surveys, the intertidal work can be far more flexible and 'adaptive', Because the ground is easily seen, decisions can be made *during the survey* to adjust the sampling plan to make sure the sampling sites are located in the most representative areas. Ad-hoc sampling is also possible, for example running a transect across a gradual change in sediment type that is recognised 'in the field' but was no obvious in the remotely sensed data.

A likely optimal sequence for intertidal ground truth surveys is summarised in the flow diagram, and further details are provided in the Case Study Optimising intertidal zone field work.doc .

The latter example goes on to explain that, the knowledge gained from the physical ground-truth sampling is used to make a more refined interpretation of the remotely sensed data to produce a morpho-sediment map. If the remotely sensed data includes digital imagery, automated or semi-automated classification techniques can be used. If only photographs are available, the interpretation relies on informed expert judgement. Knowledge gained from the biological ground truthing is used to further refine the map, identifying and delineating bio-physical habitats according to the classification system being used (e.g. EUNIS). The final map is then validated using the validation data set.

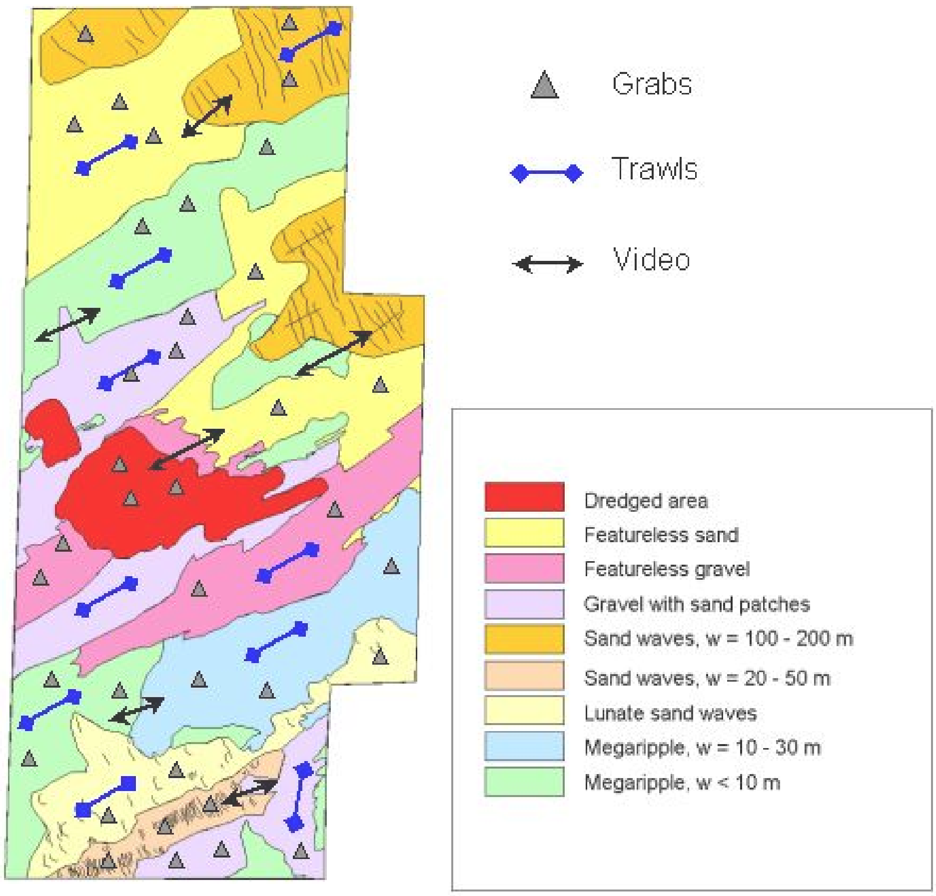


In shallow water areas, the ground truthing strategy is similar, with the exception that sampling and observations are more difficult to perform. It can frequently be the case that other remote sensing techniques, such as shallow water sidescan or multibeam sonar, can be run to confirm the presence or lower depth range of kelp, seaweed and seagrass and to give cross referenced information on the nature if the seabed. Divers can be used for further observation and grabs can collect sediment samples.

Subtidal surveys

Sub-tidal ground truth surveys aim to sample ground types and /or features detected by the remote sensing surveys. It is therefore implicit that sufficient time is allowed between the remote sensing and ground-truth surveys to process and interpret the remotely sensed data and give proper consideration to planning the ground-truthing. Optimising the survey design involves selecting appropriate sampling techniques and sampling sites, and time spent here will help avoid wasted effort expended on collecting inadequate samples using inappropriate gear at unrepresentative sites.

It is good practice to use a suite of complementary techniques that, in combination, provides information on the nature of the sediments and their associated infauna and epifauna. In the hypothetical plan illustrated below, the seabed facies are targeted with grabs to sample sediments and infauna, and trawls to sample epifauna. A video sledge is used to target and verify the apparent boundaries between facies.

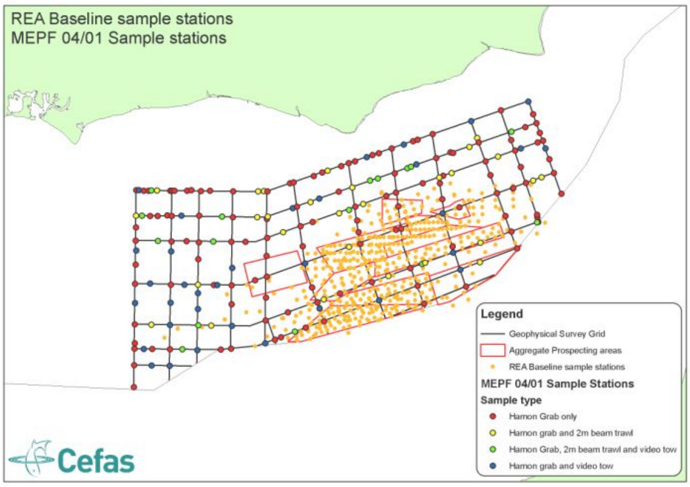


Possible survey design for ground-truth sampling of a draft physical map interpreted from a sidescan sonar surveys. The area is approximately 4 x 10 km

On harder substrates (cobble, boulder and rock) there is a far more limited selection of effective sampling techniques. Although it may be possible to collect a physical sample with heavy dredges, any biological material they return is usually severely damaged. Instead, observational techniques are preferred, using a combination of video and stills imagery.

Sampling sites should be selected to give good spatial coverage over the whole study area and some degree of replication within the different ground-types identified by the remote survey. It can often be impractical to sample every occurrence of every ground type, but the minimum requirement would be to sample each ground type at least once, as without a ground-truth sample the ability to classify the ground –type as a habitat is severely limited. Stratified sampling will be required in areas where there is a clear environmental stratification, such as a significant change in depth or salinity, so each class of ground type may need to be samples in each environmental stratum.

For surveys over larger 'regional' spatial scales, it is not practical to sample with the same level of intensity used for area- or site- scale studies, where 100% acoustic coverage has been achieved. Often, broadscale or regional studies may have only partial acoustic coverage, so ground-truth sampling will be limited to those areas, again targeting features identified by the remote sensing. Again a suite of sampling techniques should be used, but in practice cost limitations often preclude the use of all the techniques at every sampling station, so pragmatic decision need to be made about which technique(s) will be used at which stations. This requires dedicated planning and detailed scrutiny of the available acoustic data to inform the choice of sampling gear at each potential sampling station. The following case study shows how a regional-scale geophysical survey was ground-truthed for the Eastern English Channel Marine Habitat Map (James et al., 2007)

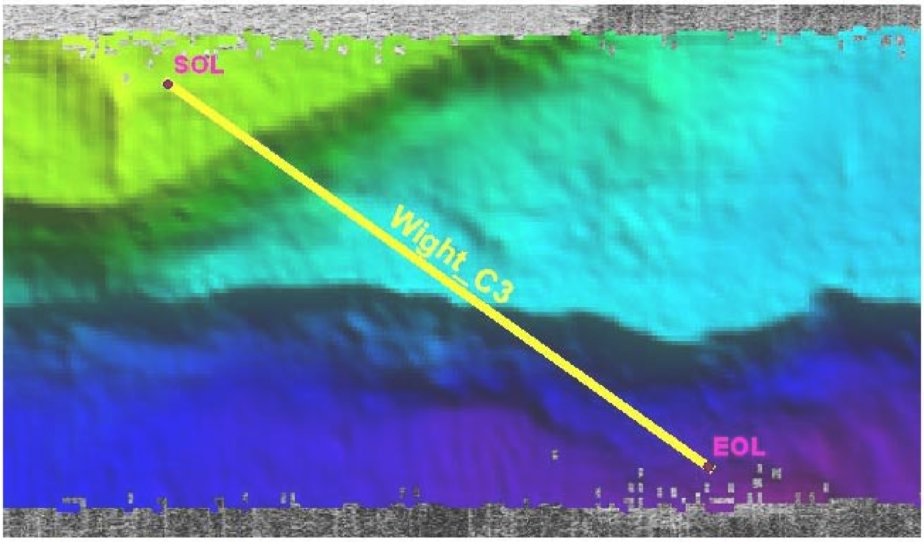


Ground-truthing: E. English Channel Marine Habitat Map

Case study on ground-truthing for the Eastern English Channel Marine Habitat Map (EECMHM)

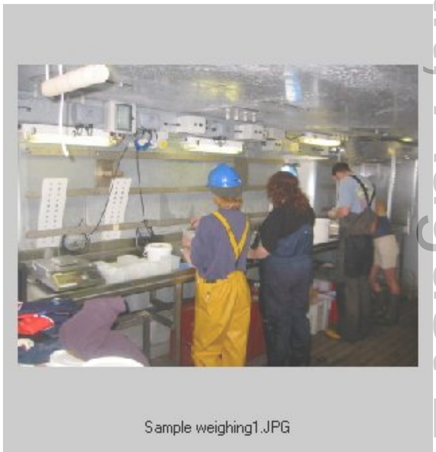
Once the requirements of the ground-truth survey have been established (i.e. the sampling frequency, sampling gear and sampling stations) attention should be paid to the survey logistics, so that most efficient use is made of the available vessel time. The detailed survey plan should be discussed with the Master of the vessel to highlight any potential problems in occupying sampling stations (i.e. if they happen to fall within a traffic separation scheme, or there are local navigational hazards such as static fishing gear or obstructions on the seabed).

Where video techniques are to be used (especially ROVs), certain stations may need to be sampled at or around slack-water times to avoid periods of high current and turbidity. For video transects, there may be a preferred direction in which the transect is run, for example towing a sledge up a slope, into the tide, or from clean grounds into rough grounds so the transect can be terminated when ground conditions become too rough (rather than landing on rough grounds and having to abort the tow). Also, it is often preferable to guide a drop-camera down a steep rock face rather than up, as this reduces the chance of the camera frame snagging on the rock.



Planning a drop-camera video transect over a steeply sloping seabed feature identified by multibeam sonar (green areas are shallow e than blue). Starting the line at the top of the feature (SOL) and ending at the bottom (EOL) ensured the camera would not be dragged up the rock-face. (Image by Cefas)

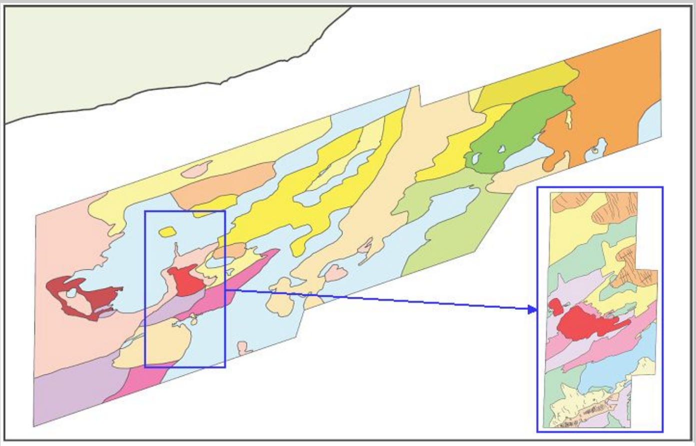
Efficiencies can also be achieved by partitioning vessel time for certain activities, such as completing grab and trawl sampling during the day time and conducting video/photographic sampling at night. This can save significant amounts of time repeatedly swapping back and forth from the grab/trawl gears to the video gear. It also makes more efficient use of personnel. As a larger team of people is usually required to collect and sort grab and trawl samples than to run the video gear, mixing the sampling and the video work may leave several personnel in the team 'redundant' during the video work.



Survey planning includes considering how many personnel are needed and organising the sampling programme to make most efficient use of their time. Here, staff on the RV Cefas Endeavour are sorting and processing a trawl sample (photos by Cefas)

A case study relating to a nested survey design around a licensed aggregate extraction site in the eastern English Channel is presented in the file EEC

Aggregates Case Study1.pdf .T his study is further illustrated in a PowerPoint slide show EEC nested survey.pps .



E. English Channel nested surveys

EEC nested strategy.jpg

Links to other sections in the MESH Guide:

How do I collect my data?

How do I make a map?

How good is my Map?

Links to other topics in the current section:

Physical information

Biological information

Optimise the ground-truthing

Ground-truth survey strategy

EUNIS levels 3, 4 & 5

Selecting a suite of tools

Ground-truth Survey Design

Selecting a suite of tools

Ground-truth Survey Design

scoping report

survey specification

Ground-truthing Techniques

Suitability of survey tools

Complementary ground-sampling techniques

Intertidal surveys

Subtidal surveys

ground-truth survey strategy

Subtidal ground-truth surveys

Links to resources:

MESH_Standards_&_Protocols_2nd Edition_26-2-07.pdf

OAA worked example v1.doc

Validating the digital terrain model.doc

Optimising intertidal zone field work.doc

EEC Aggregates Case Study1.pdf

EEC nested survey.pps

Links to other websites:

http://www.jncc.gov.uk/page-2684

Conducting surveys

When completed, the outcomes of the planning process will clearly identify:

- What I want to map (scoping report: aims).
- Why I want to map it (scoping report: objectives).
- Where I need new data (gap analysis).
- What new field surveys are required to collect that data (survey programme, survey strategy/design, selection of tools).

With this information you are ready to prepare for the field work. This includes drawing up detailed lists of the necessary equipment, which should include sufficient spares to cover the risks of equipment failure.

To assure the quality of the data that will be collected it is important to follow recognised procedures when using equipment in the field. There are many existing standards and protocols for the conduct of survey work, but these differ according to the specific purpose of the survey task, and may exceed or fail to meet the requirements for habitat mapping. Therefore, in the next section *How do I collect the Data?* we set out a series of Recommended Operational Guidelines for using each of the survey techniques in the context of a habitat mapping project.

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